NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

DISTRIBUTED AND END-TO-END TESTING

by

BeEm V. Le

December 2009

Thesis Advisor:	Thomas V. Huynh
Second Reader:	Raymond Barrera

Approved for public release; distribution is unlimited

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2009	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Distributed and End-to-End Testing **6. AUTHOR(S)** BeEm Van Le	**5. FUNDING NUMBERS**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Many U.S. Navy systems were built on the fly and have encountered interoperability problems at sea, such as erroneous dual/multiple track designations, misidentification/track identity conflicts, report responsibility conflicts, friendly tracks displayed as unknown/pending, tracks dropped without operator action, different track identities of at different ships, etc. To identify and fix these interoperability problems, the Navy instituted the Distributed Engineering Plant (DEP) testing program, run by the Naval Sea Systems Command (NAVSEA), and the End-to-End (E2E) testing initiative, currently formed by the Space and Naval Warfare Systems Command (SPAWAR). Whereas the DEP involves many land-based laboratories across the U.S. connected via an Asynchronous Transfer Mode (ATM) network, E2E testing is carried out entirely at one laboratory—the E2E lab. The DEP testing program is faced with the problem of determining a cost-effective way of paying for testing—providing the participant DEP laboratories full-time funding or paying them on a per-test basis. A challenge faced by the E2E testing program is getting the E2E lab ready for testing. Two factors contributing to this challenge are uncertain availability of funding for building the E2E lab and the lack of a comprehensive plan to establish the E2E lab. Such a plan calls for a rigorous justification of the E2E lab needs and hence funding requirements. This thesis performs an in-depth examination and a qualitative analysis of the two testing programs and a quantitative comparative analysis of the DEP testing program's paying options and, using goal programming, provides data in support of creating an E2E lab plan. The significance of this thesis is the use of analysis and mathematical programming to provide analytical data in supporting informed decision making in testing and evaluation of systems and/or systems of systems.

14. SUBJECT TERMS Distributed, End-to-End, Combat Systems, C4I Systems, Pay-per-Test, Goal Programming (GP), Distributed Engineering Plant (DEP), E2E Lab, PMW, PEO C4I, NAVSEA, SPAWAR	**15. NUMBER OF PAGES** 81
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTED AND END-TO-END TESTING

BeEm V. Le
Department of the Navy
B.S., Bradley University, 1987

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 2009

Author: BeEm V. Le

Approved by: Dr. Thomas V. Huynh
Thesis Advisor

Mr. Raymond Barrera
Second Reader

Dr. Cliff Whitcomb
Chairman, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Many U.S. Navy systems were built on the fly and have encountered interoperability problems at sea, such as erroneous dual/multiple track designations, misidentification/track identity conflicts, report responsibility conflicts, friendly tracks displayed as unknown/pending, tracks dropped without operator action, different track identities of at different ships, etc. To identify and fix these interoperability problems, the Navy instituted the Distributed Engineering Plant (DEP) testing program, run by the Naval Sea Systems Command (NAVSEA), and the End-to-End (E2E) testing initiative, currently formed by the Space and Naval Warfare Systems Command (SPAWAR). Whereas the DEP involves many land-based laboratories across the U.S. connected via an Asynchronous Transfer Mode (ATM) network, E2E testing is carried out entirely at one laboratory—the E2E lab. The DEP testing program is faced with the problem of determining a cost-effective way of paying for testing—providing the participant DEP laboratories full-time funding or paying them on a per-test basis. A challenge faced by the E2E testing program is getting the E2E lab ready for testing. Two factors contributing to this challenge are uncertain availability of funding for building the E2E lab and the lack of a comprehensive plan to establish the E2E lab. Such a plan calls for a rigorous justification of the E2E lab needs and hence funding requirements. This thesis performs an in-depth examination and a qualitative analysis of the two testing programs and a quantitative comparative analysis of the DEP testing program's paying options and, using goal programming, provides data in support of creating an E2E lab plan. The significance of this thesis is the use of analysis and mathematical programming to provide analytical data in supporting informed decision making in testing and evaluation of systems and/or systems of systems.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACDS	Advanced Combat Direction System
ADNS	Advanced Digital Network System
ADSI	Air Defense System Integrator
AI	Auto Identification (ID)
APIT	Advanced Platform Interoperability Assessments Test
AT&T	American Telephone & Telegraphic
ATM	Asynchronous Transfer Mode
AWS	Aegis Weapons System
ASW	Air & Surface Warfare
BFIT	Battle Force interoperability Test
BMC4I	Battle Management Command, Control, Communications, Computers, and Intelligence
BPIT	Basic Platform Interoperability Assessments Test
C2P	Command and Control Processor
CA	California
CANES	Consolidated Afloat Networks and Enterprise Services
CDLMS	Common Data Link Management System
CDSA	Combat Direction Systems Activity
CEC	Cooperative Engagement Capability
CG/DDG	US Navy Cruiser Ship/US Navy Destroyer Ship
CM	Configuration Management
COTS	Commercial of the Shelf
CS	Combat Systems
CSCS	Center for Surface Combat Systems, Dahlgren, VA
CSEDS	Combat System Engineering Development Site, NJ (New Jersey)
CV/CVN	US Navy Aircraft Carriers and Nuclear Aircraft Carriers
D-30	Navy D-30
DEP	Distributed Engineering Plant
DIS	Distributed Interactive Simulation
DISN-LES	Defense Information System Network - Leading Edge Services

DNS	Domain Name Server
DOC	DEP Operations Center
DoD	Department of Defense
E2C	E-2 Hawkeye
E2E	End-to-End
FIT	Force Interoperability Test
FY	Fiscal Year
GCCS-M	Global Command and Control System-Maritime
GP	Goal Programming
I/O CERT	Interoperability Certification
I/O DEV	Interoperability Development
IA	Interoperability Assessment
IA	Information Assurance
IADT SYS-2	Integrated Automated Detection and Tracking System - 2
ICSTD	Integrated Combat Systems Test Detachment
ID	Identification
IWSL	Integrated Weapons Systems Lab
LHD	Landing Helicopter Dock (US Navy Ship)
LOS	Line of Sight
LP	Linear programming
Mbps	Megabits per second
MD	Maryland
MTBF	Mean time between failures
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAWCAD-AIL	Naval Air Warfare Center, Avionics Integration Laboratory, China Lake, CA
NOC	Network Operation Center
NSWC	Naval Surface Warfare Center
NSWC CDSA	Naval Surface Warfare Center, Combat Direction Systems Activity Dam Neck, VA
NSWC Corona	Naval Surface Warfare Center, Corona, CA

NSWCPHD	Naval Surface Warfare Center, Port Hueneme Division, Detachment San Diego, CA
NTDS	Naval Tactical Data System
OPNAV	Office of the Chief of Naval Operations
OR	Operations Research
PEO C4I	Program Executive Officer Command, Control, Communications, Computers, and Intelligence
PM	Project Manager
PMW	Program Manager Warfare
POM	Program Objective Memorandum
RLBTS	Reconfigurable Land-Based Test Site
SATCOMs	Satellite Communications
SCSC	Surface Combat Systems Center
SE	Systems Engineering
SGS/AC	Ships Gridlock System/Automatic Correlation
SIF	Systems Integration Facility
SIMS/STIMS	Simulations/Stimulators
SIPRNET	Secret Internet Protocol Router Network
SME	Subject Matter Expert
SOA	Service-Oriented Architecture
SPAWAR	Space and Naval Warfare Systems Command
SSC-PAC	SPAWAR Systems Center-Pacific
SSDS	Ship's Self Defense Systems
S-TADIL J	Satellite Tactical Digital Information Link J
SYSCOM	Systems Command
T&E	Test and Evaluation
TACCOMM	Tactical Communications
TAS MK-23	Target Acquisition System Mark-23
TPX-42	The Interrogator Set - 42
TR	Trouble Report
VA	Virginia
VPN	Virtual Private Network

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Distributed and End-to-End Testing in the U.S. Navy

Dealing with test and evaluation of combat and Command, Control, Communications, Computers and Intelligence (C4I) systems in the U.S. Navy, this thesis focuses specifically on two separate Navy testing programs managed by two different commands: the Distributed Engineering Plant (DEP) testing program, run by the Naval Sea Systems Command (NAVSEA), and the End-to-End (E2E) testing program, currently formed by the Space and Naval Warfare Systems Command (SPAWAR).

During past deployments and Battle Group exercises, Battle Group systems encountered interoperability problems such as erroneous dual/multiple track designations, misidentification/track identity conflicts, report responsibility conflicts, friendly tracks displayed as unknown/pending, tracks dropped without operator action, different track identities of different ships, etc. As new technologies and commercial-off-the-shelf (COTS) products, used in the development of the systems, changed rapidly (items usually becoming obsolete in a couple of years), and lacked backward compatibility, the systems failed to work together, thereby resulting in those interoperability problems. When these interoperability problems occurred at sea, fixing them was costly because of the high cost incurred in bringing subject matter experts from land to ships to correct the problems. In an effort to prevent these costly problems, the DEP testing program was formed in June 1998 to support the evaluation of the interoperability of Battle Group systems and also to aid in design decision making early in the systems acquisition process.

The DEP consists of shore-based combat system sites such as the Naval Surface Warfare Centers (NSWC) in Dahlgren, Dam Neck, Wallops Island, and San Diego; the SPAWAR Systems Center-Pacific (SSC-PAC); and the Naval Air Systems Command (NAVAIR) Paxtuxent/China Lake. These combat system sites, connected via an Asynchronous Transfer Mode (ATM) network provided by Defense Information Systems Agency (DISA) and using Defense Information Systems Network-Leading Edge Services (DISN-LES), replicate, to the maximum extent possible, hardware, computer programs, connectivity, and the environment of the ship and aircraft combat systems. To replicate a

Battle Group, the DEP would include the combat system sites representing the members of the Battle Group. A combat system would be connected, not to all sites, but only to the sites that could serve as test beds for the required platform combat systems.

The purpose of the E2E testing is to evaluate integrated capabilities of shipboard C4I systems for interoperability. The shipboard C4I systems, which provide enhanced, integrated C4I capabilities through integrated communication and information technology systems that would deliver end-to-end connectivity to aid in achieving decision superiority, need be tested before their delivery to the warships, with the hope to prevent interoperability failures from occurring while the warships are at sea. In addition, not only does the E2E testing support the certification, but it also supports the developmental testing of multiple programs. Concentrated mainly on C4I systems, the E2E testing program emphasizes the area of services, such as Domain Name Server/Email/Web; communication systems, such as Consolidated Afloat Networks and Enterprise Services/Advanced Digital Network System/Teleport/Network Operation Center; Information Assurance, such as Gold Disk/Virtual Private Network/Cryptos; and networks, such as Satellite Communications & Line of Sight & Pierside. In the future, the E2E testing may be expanded to include systems outside of the C4I arena.

In the E2E testing concept, formulated in 2007, a single E2E systems engineering laboratory, which is yet to be built, replicates and tests these C4I systems. The E2E lab is to house as much C4I hardware as possible in order to support the E2E testing. Limited in funding, the E2E testing program plans to employ test engineers from the Program Manager Warfare (PMW) organizations and to have a lab manager, a lab technician, network engineers, and systems administrators to perform day-to-day lab activities.

A challenge faced by the E2E testing program is building and getting the E2E lab ready for testing. Two factors contributing to this challenge are uncertain availability of funding for building the E2E lab and the lack of a comprehensive plan to establish the E2E lab. Such a plan calls for a rigorous justification of the E2E lab needs and hence funding requirements. Analytical support is needed to provide rigorously obtained data to aid in the formulation of such a plan.

With a focus on the issue of cost-effective implementation of the DEP and E2E testing programs, the research performed in this thesis involves (1) conducting a review of the past and current test results of the distributed, E2E programs and their archived documents, related distributed and E2E testing studies, and other pertinent related material such as test reports, test plans, and test procedures; (2) developing interview questionnaires directed at managers of the DEP and E2E testing programs; (3) conducting interviews with the DEP and E2E testing program managers, test directors, functional leads, and process literature and interview results; and (4) performing qualitative and quantitative analysis and goal programming to aid in determining the optimal costs of carrying out these testing methods.

The findings from this research follow.

DEP Testing Program

- The DEP program currently pays the DEP participant sites on a per-test basis, rather than on a retaining full-time basis. Perceived by the DEP program as a cost-effective paying concept, the pay-per-test method does not pay the DEP sites to retain engineers upon the completion of testing. When a test is completed, the DEP participant sites, whose funding is now depleted, lose the experienced engineers. When a new test or retest is needed, newly hired engineers, who have little or no knowledge of the program, use a major portion of the allocated testing time to learn and set up the test. Also, when any of the DEP sites has trouble and consequently cannot join the remaining DEP sites for testing as planned, the latter have to wait until the troubled site is fixed. As a result, the allocated testing time is not fully used for testing. The data analysis in this research indicates that roughly 38% of the allocated testing time is lost at the beginning of a test. The time loss, resulting from the current pay-per-test practice, remains a major issue the DEP program needs to resolve.
- Another paying option for the DEP program to consider is paying the DEP participant sites a fixed amount of money to retain full-time engineers. This

option is not necessarily cost-effective as the sites will constantly deplete funding, whether they are doing testing or staying idle. Using the testing cost data from FY01-FY09, during which the number of tests carried out ranges from three to eight per year, the comparative analysis performed in this research, evaluating the two options—pay-full-time or pay-per-test—indicates that conducting eight tests during FY09 with two engineers, using the pay-per-test method costs approximately $3.8M whereas using the full-time payment method costs about $2.7M. Furthermore, the analysis indicates that if the number of tests per year is not greater than six, the pay-per-test method is cheaper than the pay-full-time option and that if more than six tests per year are carried out, the full-time option is cheaper than the pay-per-test option. As six or less tests are conducted for only two out of the nine years (FY01 and FY05), the pay-full-time option would have collectively saved money during FY01-FY09. In this case, the core experienced engineers would have been likely retained and the lost time would have been reduced, if not eliminated. Thus, in the long run, if more than six tests are conducted, savings will be made with the pay-full-time option. Finally, if the number of tests is less than six per year, the DEP program has the flexibility in selecting either of the paying options.

E2E Testing Program

- Using testers from the PMWs, as currently planned by the E2E testing, is not a desirable approach, as the PMW testers would leave after completion of the testing and would also take with them their knowledge, which might not be available when needed for additional testing. This approach would possibly lead to the time loss problem faced by the DEP program; a lack of accountability as different PMWs from which testers come would claim effectiveness when, in actuality, history has shown otherwise; finger pointing in the case of failure; difficulty in timely coordination and flexibility of schedule in order to support the E2E testing program; and possibly not meeting the schedule.

- Rather being Program Objective Memorandum (POM) funded, the E2E testing program secures its funding from taxing the PMWs. As such funding is uncertain, the E2E testing program might not be sustainable in the future.

- The first planned E2E testing event scheduled for December 2008 of the Lincoln Battle group did not happen because the E2E lab has not been built yet. Funding uncertainty and the lack of a complete plan to establish the E2E lab contribute to the delay in building and getting the E2E lab ready for testing.
- Toward the formulation of a comprehensive plan to build the E2E lab, the use of goal programming is demonstrated in this thesis. The demonstration reveals that, for the scenario treated in this research, the planned cost for building the E2E lab, which is $650,000, exceeds the optimal cost obtained with the goal programming approach, which is $647,000, by $3,000. Whereas money savings are realized, the targeted number of desks and chairs is short by one. This negligible shortage is acceptable.
- Finally, goal programming can be used as a rigorous approach to determining the goals of the E2E lab in a timely fashion (hence, saving money) that can meet budgetary constraints. The E2E testing program can use this approach to justify the funding for the current year and future funding. The goal programming approach can also be used in support of planning for programs other than testing as well as for many multi-goal problems encountered in systems engineering. Results obtained with this goal programming approach are used in decision making, in assessing the feasibility of achieving the goals, and also in knowing how much determining funding is required to meet the goals.

Recommendations

- Fund the DEP sites on a pay-per-test basis if no more than six tests are performed in a year; otherwise, fund the DEP sites on a full-time basis.

- Retain the core engineers to run DEP tests.

- Employ optimization techniques in general and goal programming in particular in planning for and, specifically, in formulating a plan for building the E2E lab.
- Employ rigorous approaches — analytical and/or optimization techniques — from the beginning of testing programs to plan for and implement the testing programs.

Areas for Further Research

- Test and evaluation communities may extend the analysis and optimization techniques discussed in this thesis to determine the optimal methods of conducting tests with constraints on resources such as laboratories, personnel, schedules, etc.
- The approach espoused in this thesis may serve as a foundation for additional research and studies of the joint distributed testing/coalition distributed testing.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Tom Huynh, for his extensive support, patience, encouragement, and most of all his knowledge. I appreciate the time he has spent in helping me achieve my goals. Without his help and support, I would not be able to complete this program.

I would also like to extend my appreciation and thanks to Raymond Barrera for his support, encouragement, and his positive attitude. He has continuously encouraged me to not to give up, and to keep pressing on to obtain this Master's degree program.

I would like to thank my sister, Michele Le, my niece, Mimi Luong, and my son, Minh Le, for proof reading and making recommendations to improve my thesis.

Last but not least, I would like to thank my family for their support, encouragement, and understanding during the past two years. They are my strength and motivation.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

This thesis deals with some aspects of test and evaluation of systems in the U.S. Navy. Specifically, this thesis focuses on the distributed testing and end-to-end (E2E) testing programs. Briefly, whereas distributed testing involves many geographically distributed sites (labs) that are interconnected to carry out a test, E2E testing is carried out entirely in one lab (at one site). By virtue of the purposes of these test programs, only combat systems and command, control, communications, computers, and intelligence (C4I) systems are subjects of testing.

Interoperability among the Fleet units in deployment fails as a result of erroneous dual/multiple track designations, misidentification/track identity conflicts, report responsibility conflicts, friendly tracks displayed as unknown/pending, tracks dropped without operator action, etc. (Monteith, 2001). In the absence of a test and evaluation program, fixing these interoperability failures adversely affected the Fleet's missions. In one instance, a Battle Group was deployed without two modern combatants, as the latter were tied to a pier in order to have interoperability problems fixed. In another instance, a great deal of time during the final six months prior to a Battle Group deployment was consumed, not by training, but by "debugging" of systems in the Battle Group. These unacceptable instances called for a systematic testing and evaluation approach to deal with the interoperability problems (DEP, 2005).

To address combat systems interoperability problems across Battle Management Command, Control, Communications, Computers and Intelligence (BMC4I)/combat systems and to work with the Fleet to fix the interoperability problems, the Naval Sea Systems Command (NAVSEA), in April 1998, formed the Combat System Interoperability Task Force, whose objectives were to examine the interoperability crisis and to provide recommendations and/or solutions for fixing the interoperability problems. To achieve these objectives, the Task Force determined the feasibility and cost of using a land-based distributed engineering plant (DEP) to support the design, development,

testing, and evaluation of Battle Group systems (DEP, 2005). In June 1998, the DEP was established, signifying the beginning of the Navy's distributed testing.

Distributed testing has, however, encountered the difficulty of getting all the labs together and having all resources available at one time to form the DEP. The DEP program currently pays the DEP participant sites on a per-test basis, rather than on a retaining full-time basis (Mann, 2004). Perceived by the DEP program as a cost-effective paying concept, the pay-per-test method does not pay the DEP sites to retain engineers upon the completion of testing. When a test is needed, inexperienced part-time engineers are hired to perform the test. This practice has led to testing inefficiency, namely, the loss of test time to setting up the labs by inexperienced part-time engineers, and need to be evaluated against the full-time paying option. One of the goals of this thesis research is to perform analyses to aid the DEP program manager (PM) in making the correct decision in paying the DEP labs for testing. Chapter II discusses in detail the DEP testing program and its problems/issues.

The concept of E2E testing in the Navy began in 2007, when Office of the Chief of Naval Operations (OPNAV) tasked the Navy Program Executive Officer Command, Control, Communications, Computers, and Intelligence (PEO C4I) to provide enhanced, integrated C4I capabilities through integrated communication and information technology systems that would deliver end-to-end connectivity to aid in achieving decision superiority (Miller, 2008). These integrated communication and information technology systems often make use of commercial of the shelf (COTS) technologies. When these systems encounter problems at sea, fixing them can become costly because of the high cost incurred in bringing subject matter experts (SMEs) from land to ships to correct the problems at hand. Requested by PEO C4I to provide support in solving this cost problem, the Space and Naval Warfare (SPAWAR) Systems Center-Pacific (SSC-PAC) is building an E2E Systems Engineering (SE) lab (E2E SE, 2008), which will replicate and test multiple shipboards C4I systems before their delivery to the Fleet. Building the E2E lab can be costly, and the utilization of the E2E lab, along with the use of personnel, is also an issue. The second goal of this thesis research is to analyze the current approach to building the E2E lab and to explore the use of goal programming as an optimization

tool to aid the E2E testing PM in optimally formulating a plan to build the E2E. Chapter III discusses in detail the E2E testing effort and its problems/issues.

The rest of this chapter discusses the purpose of the thesis (Section B), the research questions (Section C), the potential benefits of the thesis (Section D), the scope and the research methodology (Section E), and the organization of the remaining of the thesis (Section F).

B. PURPOSE

With a focus on the issue of cost-effective implementation of the DEP and E2E testing programs, the research performed in this thesis identifies the issues and problems encountered by the DEP and E2E testing programs; examines available information and data from the two programs; performs qualitative and quantitative analyses to provide data to aid the DEP testing program with its implementation; and explores and applies goal programming to support the formulation of a plan to build the E2E lab.

C. RESEARCH QUESTIONS

The primary questions are:

1. How does the Navy employ distributed testing and E2E testing?
2. Can optimization methods be used to aid in determining the minimal cost in implementing these testing methods while maximizing the use of available resources (personnel and lab hardware)?

Answering these questions amounts to answering the following secondary questions:

a. What are the differences between the distributed testing and E2E testing programs?
b. What are the current methods used by the Navy to conduct distributed and E2E testing?
c. How does the Navy employ these testing methods for testing of naval combat systems?

d. What analysis and optimization methods that can be used to aid in determining the minimal costs of carrying out these testing methods while maximizing the use of lab resources (including hardware and personnel)?
e. What recommendations regarding the implementation of these testing methods can be provided to the Navy?

D. RESEARCH BENEFIT

This thesis demonstrates the analysis and the use of goal programming methods that can be used by PMs to effectively and efficiently perform their tasks of budgeting, scheduling of lab assets, and utilization of the labs. In addition, the Test and Evaluation community may extend the analysis and optimization techniques discussed in this thesis to determine the optimal methods of conducting tests with constraints on resources such as laboratories, personnel, schedules, etc. Furthermore, the approach espoused in this thesis may serve as a foundation for additional research and studies of the joint distributed testing/coalition distributed testing.

E. SCOPE AND METHODOLOGY

1. Scope

With a focus on the issue of cost-effective implementation of the DEP and E2E testing programs, the research performed in this thesis identifies the issues pertaining to the two major problems encountered by the DEP and E2E testing programs; examines available information and data from the two programs; performs qualitative and quantitative analyses to provide data to aid the DEP program with its implementation; and explores and applies goal programming to support the formulation of a plan to build the E2E lab.

2. Methodology

The research methodology involves:

a. Conducting a review of the past and current test results of the distributed, E2E programs and their archived documents, related

distributed and E2E testing studies, and other pertinent related material such as test report, test plans, and test procedures;

b. Developing interview questionnaires directed at managers of the DEP and E2E testing programs;
c. Conducting interviews with the DEP and E2E testing PMs, test directors, functional leads, and process literature and interview results;
d. Performing qualitative and quantitative analysis and goal programming to aid in determining the optimal costs of carrying out these testing methods; and
e. Formulating recommendations to the Navy regarding the implementation of these testing methods.

F. THESIS ORGANIZATION

The rest of the thesis is organized as follows. Chapter II discusses the DEP testing program. Chapter III discusses the E2E testing program. Chapter IV presents the analyses of both the DEP and E2E testing programs. Chapter V discusses the comparative analysis for aiding the DEP testing program in making paying decisions and the goal programming approach in supporting the E2E testing program. Chapter VI contains the conclusions and recommendations on future research.

THIS PAGE INTENTIONALLY LEFT BLANK

II. DISTRIBUTED ENGINEERING PLANT PROGRAM

A. INTRODUCTION

This chapter provides the background of and the problems encountered by the DEP program. As mentioned in Chapter I, the Navy DEP was formed to aid in solving interoperability problems such as communications between ship systems, common operational pictures between ships, incorrect IDs, dual tracks, etc. that occurred during deployments and Battle Group exercises (Monteith, 2001). Interoperability problems encountered by combat ships have had their roots in the use of commercial-off-the-shelf (COTS) products and new technologies to develop systems. As technologies change rapidly (items usually becoming obsolete in a couple of years) and backward compatibility of some items has been a common phenomenon, the use of COTS and constant technological advances has created acquisition problems not only for the Navy, but also for the Department of Defense (DoD). Interoperability problems have become a challenge to the Navy.

In February 1998, the Fleet reported concerns regarding interoperability failures among combat systems that were recently installed in the Fleet units (USS John F. Kennedy and USS Wasp). Debugging of glitches consumed a great deal of Fleet time during the final six months prior to Battle Group deployment (DEP, 2005). In March 1998, the Chief of Naval Operations assigned the Naval Sea Systems Command (NAVSEA) the responsibility to address combat systems interoperability problems across BMC4I/combat systems and to coordinate an effort with the Fleet to solve the interoperability problems. In April 1998, NAVSEA formed the Task Force on Combat System Interoperability to study the interoperability crisis and to provide recommendations for solutions. In June 1998, the Task Force affirmed the technical feasibility of the establishment of a DEP to support the evaluation of the interoperability of battle force systems and to enable good design decisions early in the acquisition process (DEP, 2005).

Following the Task Force Report, fourteen Navy organizations shown in Figure 1, representing the surface, air, subsurface, and C4I components across all Navy Systems Commands (SYSCOMs), formed the Battle Force Interoperability Navy Alliance (DEP, 2005) to cooperatively support the interoperability task. The initial purpose of the Navy Alliance was to develop a proposal for the establishment and implementation of a Navy DEP.

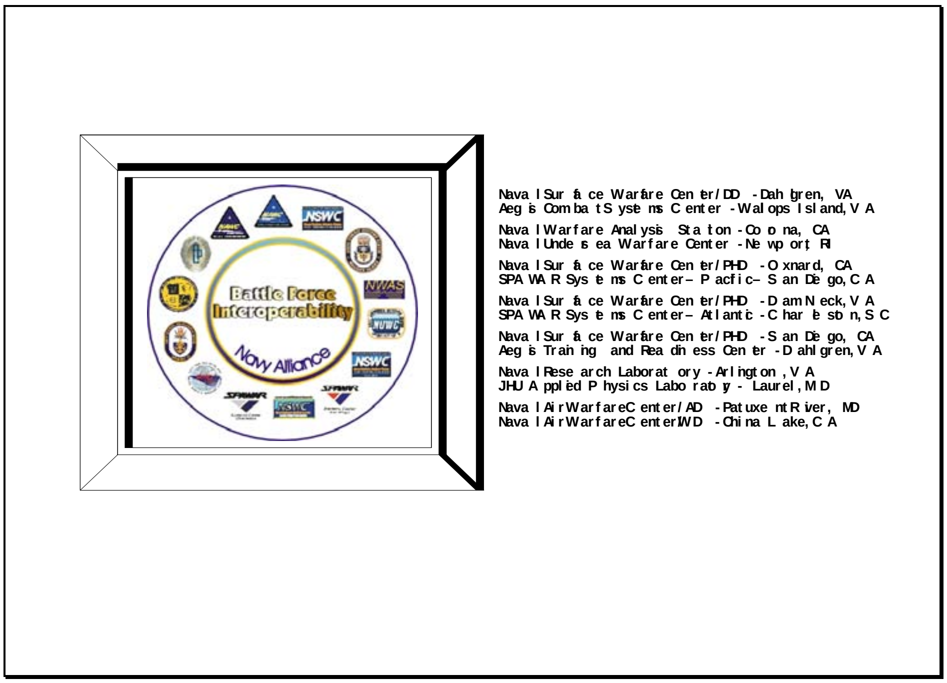

Figure 1. NAVY DEP Alliance (DEP, 2005)

The DEP consists of shore-based combat system sites such as the Naval Surface Warfare Centers (NSWC) in Dahlgren, Dam Neck, Wallops Island, and San Diego; the SPAWAR Systems Center-Pacific (SSC-PAC); and the NAVAIR Paxtuxent/China Lake. These combat system sites replicate, to the maximum extent possible, hardware, computer programs, connectivity, and the environment of the ship and aircraft combat systems (DEP, 2005). To replicate a Battle Group, the DEP is extended to include the combat system sites representing the members of the Battle Group. A combat system consists of many tightly integrated key elements. It is the brain of the ship, which acquires track data, intelligent data, situational awareness data, and displays these data on

its Display console. It interfaces with other subsystems such as radar, target acquisition, Cooperative Engagement Capability (CEC), and the Global Command and Control System Maritime (GCCS-M), etc (DEP, 2005). A combat system is to be connected, not to all sites, but to only the sites that serve as test beds for the required platform combat systems. The DEP is thus supposed to be the most cost-effective way to perform interoperability testing.

The remaining of this chapter is organized as follows. Section B discusses the Navy systems tested with the DEP; Section C the evolution of DEP testing objectives and names; Section D the DEP network architecture; Section E DEP test scheduling; Section F DEP staffing; and Section G DEP test results. Section H provides a brief summary of the chapter.

B. NAVY SYSTEMS TESTED WITH THE DEP

The DEP is intended to test all of the Navy's systems, specifically combat systems as they are the most electronically integrated and their performance is related to safety required in firing weapons. DEP testing would involve the Aegis Weapons System (AWS), Advanced Combat Direction System (ACDS), radar system, navigation system, tactical data link systems, and the Global Command and Control Maritime (GCCS-M) system. As a battle group has many ships, which in turn have many combat systems (e.g., ACDS, AWS), one single lab (site) would not be able to house all or many systems, and labs (sites) across the country would be needed in testing all of these systems as illustrated in Table 1 (Coyne, 2006).

Both Integrated Combat Systems Test Detachment (ICSTD) in San Diego, CA and Combat Direction Systems Activity (CDSA) in Dam Neck, VA, house the Advanced Combat Direction System (ACDS) system; both the Integrated Weapons Systems Lab (IWSL) in Dahlgren, VA, and the Surface Combat Systems Center (SCSC) in Wallops Island, VA, house the Aegis Weapons System (AWS); the SPAWAR Systems Center—Pacific (SSC-PAC) in San Diego, CA, houses the Global Command and Control System Maritime (GCCS-M) systems; both the Patuxent River, MD and SSC-PAC in San Diego, CA, house an E-2 Hawkeye (E2C) system; and China Lake houses F-18. Systems

subjected to DEP testing include a Cooperative Engagement Capability (CEC), Auto Identification (ID), Common Data Link Management System (CDLMS)/Command and Control Processor (C2P), Ships Gridlock System/Automatic Correlation (SGS/AC), Target Acquisition System Mark-23 (TAS MK-23), Interrogator Set (TPX-42), Integrated Automated Detection and Tracking (IADT) System (SYS-2), Link-4/11/16, and Air Defense System Integrator (ADSI). Weapons or sensors that are unavailable to a combat system are then emulated by computer simulations or a stimulator (SIMS/STIMS). In addition, the SIMS/STIMS generates a common environment representing the real world and entities therein. The emulated battle group then performs within a controlled, repeatable environment under the close scrutiny of engineers and developers (DEP, 2005).

Facility/Lab	Combat Systems	Numbers of Systems Available For Use
Naval Surface Warfare Center, Port Hueneme Division, Detachment San Diego, CA (NSWCPHD - ICSTD)	SSDS MK 2 Mod 1/2 and ACDS BLK 0/1	3 (dependent on configuration requested)
Naval Surface Warfare Center, Combat Direction Systems Activity Dam Neck, VA (NSWC CDSA)	SSDS MK 2 Mod 1, ACDS Block 0/1, ADSI, and CDS	3
Integrated Warfare Systems Laboratory, Dahlgren, VA. (IWSL)	AWS 5/6/7 Baseline	2
Center for Surface Combat Systems, Dahlgren, VA. (CSCS)	AWS 2/5/6 Baseline	2
Surface Combat Systems Center, Wallops Island, VA. (SCSC)	AWS 2/5/6/7 Baseline and SSDS	2
Naval Air Warfare Center, E2C System Test and Evaluation Laboratory, Patuxent River, MD. (NAWCAD PAX – ESTEL)	Hawkeye 2000 with Mission Computer Unit (MCU)	1
Naval Air Warfare Center, Avionics Integration Laboratory, China Lake, CA. (NAWCAD – AIL)	F/A-18 (C, D, and F) Hornet	2
Space and Naval Warfare Systems Command, Systems Center San Diego, CA. Group II E2C Test Laboratory. (SSC-SD – E2C)	Group II E2C (multiple software builds supported)	1
Space and Naval Warfare Systems Command, Systems Center San Diego, CA. Reconfigurable Land-Based Test Site for Global Command and Control System – Maritime. (SSC-SD – RLBTS)	(GCCS-M elements only). GCCS-M (multiple hull and system configurations possible).	3 or more
Naval Surface Warfare Center, Dahlgren Division, DEP Operations Center, Dahlgren, VA. (NSWCDD – DOC)	Network/infrastructure, DIS, and TACCOMM monitoring/analysis, scenario control/broadcast only	N/A
Space and Naval Warfare Systems Command, Systems Center San Diego, CA. Systems Integration Facility. (SSC-SD – SIF)	ADSI, Data Link (Link-4/11/16), and TACCOMM monitoring/analysis.	N/A
Space and Naval Warfare Systems Command, Systems Center San Diego, CA. Network Operations Center. (SSC-SD – NOC)	Network/infrastructure operations, monitoring, and analysis only	N/A
Naval Surface Warfare Center, Corona, CA. (NSWC Corona)	Voice and TACCOMM monitoring and analysis	N/A

Table 1. Labs with Associated Combat Systems (Coyne, 2006)

C. EVOLUTION OF DEP TESTING OBJECTIVES AND NAMES

The original plan of the DEP stopped with “Battle Force Interoperability Test” (BFIT), focused on the area of Air & Surface Warfare (ASW) and C4I. To conduct testing, the DEP used the Navy D-30 process (DEP, 2005) to manage and test software before its delivery to the Fleet. To justify future funding to sustain the DEP program, the DEP changed its testing objectives and the test name from BFIT to Force Interoperability Test (FIT). In addition to focusing on software upgrades, DEP testing now also focused on inputs from the Battle Group commanders and sailors. With their inputs, the interoperability problems were reproducible in the lab environment and the proposed workaround along with the proposed capabilities and limitations were then communicated to the Battle Groups. FIT was then changed to Interoperability Assessment (IA) in 2005, which was then changed again in 2006 to Basic Platform Interoperability Assessments Test (BPIT) and Advanced Platform Interoperability Assessments Test (APIT). Subsequently, the name was changed to Interoperability Development (I/O DEV) and Interoperability Certification (I/O CERT), which have thus far remained unchanged (BFIMS, 2009).

Whereas the DEP concept remains unchanged, which is to ensure that interoperability and software problems are flushed out before delivery to the Fleet, the DEP testing requirements changed with the name change. Instead of testing multiple Battle Groups, the DEP testing has been concentrated on just one Battle Group with an emphasis on certification of new or upgraded software.

D. DEP NETWORK ARCHITECTURE

As discussed in Chapter I, the basic idea underlying the DEP is to connect the labs (sites) that house the systems identified in Section B of this chapter to emulate a Battle Group with its platforms and its operational environment. The inter-site connectivity emulates the various communications networks connecting the elements of a strike group and “back channel” communications for test coordination and data collection. Computer

simulations provide coordinated stimuli to the various platform subsystems at each site. The stimuli would be both representative of the operational environment and repeatable over successive test runs (DEP, 2005).

In some DEP-unrelated efforts, connecting the various laboratories using Secret Internet Protocol Router Network (SIPRNET) has failed, because of its low-bandwidth, its lack of around-the-clock availability, and attending laborious security paperwork. In the DEP approach, the laboratories are connected via an Asynchronous Transfer Mode (ATM) network using the Defense Information System Network - Leading Edge Services (DISN-LES). The high-speed ATM network is leased from AT&T. The DEP ATM network operates at 10 Mbps, but it could also operate at 45 Mbps (at a relatively low cost). Growth to 155 Mbps and beyond is achievable. This network is available 24/7; once the network is credited (usually once a year), it can be used at anytime (DEP, 2005).

E. DEP TESTING SCHEDULING

The first DEP test was performed on the replicated Lincoln and Truman Battle Groups in 1999, whose systems (marked with 'X') are listed in Table 2 (Seaver, 2004a). This first test was successfully conducted, despite the difficulty associated with the newly formed DEP initiative and caused by the unavailability of the labs already scheduled for some other events. As the DEP program matured and the fleet requirements changed (i.e., testing not only ASW but also C4I systems), the support from some of these labs began to vanish; only a handful of the labs are now actually being utilized. Even with the smaller number of labs involved, scheduling DEP tests still complicate the schedules and planning of the labs involved in DEP testing, as the labs would have to modify their schedules, which had been established months in advance. Furthermore, if the DEP test date changed, then the DEP had to re-schedule the labs again, which would create major scheduling conflicts for the labs.

When a few components malfunction during a test, the test has to be repeated. To handle the scheduling of tests and retests, the DEP uses a web-based scheduling tool to schedule the labs (DEP, 2005). This tool effectively aids the PM and site leads in scheduling and re-scheduling the labs. The tool automatically sends an email to the

participating sites alerting a need for lab access and an email to the scheduling manager indicating the availability of the requested lab. If a schedule conflict arose, the scheduling manager would then determine a feasible time for all parties involved in testing.

	CVN	LHA	CG	DDG	DD	FFG	E-2 GP II	F-14
COMBAT SYSTEM	ACDS Blk 0	ACDS Blk 0	AWS	AWS	CDS	CDS	J9VETCBA	D03B
C2P	X	N/A	X	X	N/A	N/A	N/A	N/A
SGS/AC	X	X	X	X	N/A	N/A	N/A	N/A
Auto ID	X	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TAS MK-23	X	X	N/A	N/A	N/A	N/A	N/A	N/A
TPX-42(V)8/13/14	X	X	N/A	N/A	N/A	N/A	N/A	N/A
SYS-2	X	X	N/A	N/A	N/A	N/A	N/A	N/A
GCCS-M	X	X	X	X	X	X	N/A	N/A
LINK A/J/SAT J	X	X	X	X	A	A	A/J	J
X – Indicates system under test								

Table 2. List of DEP Systems (Seaver, 2004a)

F. DEP STAFFING

Staffing has proved to be most challenging as it is related to funding and testing tools issues. Since DEP testing is not running on a continuous basis, the testers are paid only when they support the testing. In other words, the testers are paid on a part-time basis (i.e., per-test basis). The total funding allocated to a site manager is based on an estimated number of tests to run per year (Avarez, 2006). When the number of tests unexpectedly increase, the per-test based yearly funding allocation will not be sufficient to cover the testers.

Many years of DEP testing have shown that a test has never been carried out on time. The delay in testing is caused partly by hardware and software problems and partly by the high turnover rate of personnel. Usually, testers would stay in their part-time position and leave to accept an available full-time position at another organization. Often, the new personnel, who replace the departing testers, have little or no knowledge of the conducted tests and therefore are unable to troubleshoot problems that arise during the testing. Although this high turnover rate of personnel has become problematic to the

DEP program, the DEP PM has not been willing to pay full-time positions to retain these SMEs. The DEP issues of test delay, the pay-per-test concept, and a paying alternative are discussed in more detail in Chapter IV.

G. TEST RESULTS

Many DEP tests have discovered a few new problems and repeatedly revealed identical interoperability problems (Mahon, 2003b). These interoperability problems thus have not been fixed. The new problems are reported to the program offices for corrections. Some of the interoperability problems have already been documented as trouble reports (TRs) in their local databases. If the TRs were high priority which did not have the workaround, then corrections would be made during the next software upgrade. The TRs have also been presented to the Battle Group personnel.

Lessons learned and the workaround solutions have been very useful to the Fleet as the sailors, rather than the engineers and testers, now could use them to figure out the causes of interoperability failures and to do the fixing at sea. The lessons learned have been also shared with the system developers, but, parenthetically, in the absence of any mandating instructions to consider them, the developers largely tend to ignore the lessons learned. The DEP program has never implemented the lessons learned in the development of systems, because, except for a few engineers called in occasionally for root cause analysis, the engineers doing interoperability testing are not the engineers who developed the subsystems and also because the system developer would not be around to have tests repeated to deal with problems discovered during post-test data analysis and to subsequently incorporated the problem resolution in the design of the subsystems.

H. SUMMARY

To summarize, the DEP concept is to alleviate of the cost of trying to reproduce the interoperability problems encountered during the Fleet operations because of the huge cost. To be able to reproduce the interoperability problems in the DEP lab environment is an incredible accomplishment, but, after several tests, the same problems such as duplicated track numbers, dual tracks, etc. have been still observed. In addition, the

turnover of the testing personnel has been also a dilemma. Being unable to retain the core SME to support testing and to fix interoperability problems, the DEP might become one of the programs that have no value added to the war fighter. The DEP should be analyzed objectively for its effectiveness.

THIS PAGE INTENTIONALLY LEFT BLANK

III. END-TO-END TESTING PROGRAM

A. INTRODUCTION

This chapter provides the background of and the issues encountered in the E2E program. The Navy E2E testing program began in 2007, when the Navy PEO C4I was tasked to provide enhanced, integrated C4I capabilities through integrated communications and information technology systems to aid in achieving battle decision superiority (Miller, 2008). These integrated communications and information technology systems often make use of new technologies. As noted before, when the systems encounter problems at sea, fixing them become costly because of the large expenses that are incurred when SMEs are brought from land to ships to correct the problems. The idea of E2E testing is to leverage the knowledge and existing laboratories on the campus (not across the country as in the DEP testing program) and within a command (not across different commands as in the DEP testing program) to ensure that C4I technical solutions are designed, developed, tested, certified, and delivered to a warship before its deployment (Musson, 2008b). In addition, not only does the E2E testing support the certification, but it also supports the developmental testing of multiple programs. Requested by PEO C4I to provide support in an effort to cutting such expenses, the SSC-PAC has begun to build an E2E lab intended to replicate and test shipboard C4I systems before their delivery to the Fleet. Building the E2E lab is a challenge because the sponsor pays only a fix amount of funding. The E2E testing PM must therefore analyze the E2E tasks carefully, identify the needs the E2E lab must satisfy, and determine the minimal cost to build the E2E lab.

The rest of the chapter is organized as follows. Section B discusses the E2E testing concept; Section C E2E testing program cost; Section D E2E test scheduling; Section E E2E staffing, and Section F E2E test results. Section G ends with a summary of the chapter.

B. END-TO-END TESTING CONCEPT

SSC-PAC currently manages the E2E testing program and the building of the E2E lab. The E2E lab is to house as much C4I hardware as possible in order to support the E2E testing. Required by the program office and the Fleet, the E2E C4I systems shown in Table 3 are to be tested in the E2E testing program and are thus to be housed in the E2E lab (Musson, 2008a) .

Limited in funding, the E2E testing program plans to employ test engineers from the PMWs and to have only a lab manager, a lab technician, network engineers, and systems administrators to perform day-to-day lab activities. With all the C4I systems in one lab, the idle time observed in the DEP program would be eliminated. Envisioned by the PEO C4I, the E2E testing concept is intended (Musson, 2008b):

- To ensure the complex system-of-systems capabilities are engineered, tested and certified to work together in a collaborative environment with transparency and access across the PEO C4I portfolio of solutions.
- To support the development of service-oriented architecture enterprise, in which the system is a collection of components and services developed by multiple programs.
- To provide access to developers, testers, and users of reference implementations of systems/components and to make sure that they all interact together without having to procure them.
- To provide an environment for configuration management, base lining interoperability, functionality, and performance.
- To have the E2E lab operated by an E2E system engineering team and to allow events to be staffed by PMs and stakeholders.
- To have the E2E lab shared by multiple PEO C4I sponsored projects.
- To provide mission scenarios and test strings for Unstructured, Structured, Pre-production, and Production Environments operating at multiple classifications (unclassified, confidential, and secret).

E2E C4I Systems				
Structured Environment	CFn	MEDAL	ADNS	DMS
SATCOM	DCGS-N	NITES	ISNS (V)	DMS Proxy
ADNS	DMS	Radiant Mercury	USWDSS	GCCS-J
ISNS (V)	DMS Proxy	TBMCS	AIS	GCCS-J w/I3
USWDSS	GCCS-J	NECC (Small Footprint)	C2PC	GCCS-M
AIS	GCCS-J w/I3	Pre-Production	CFn	MEDAL
C2PC	GCCS-M	SATCOM	DCGS-N	NITES
Radiant Mercury	TBMCS	NECC (Small Footprint)		

Table 3. E2E C4I Systems (Musson, 2008a)

The E2E testing PM, interviewed in this research, believes that E2E testing will save the PEO C4I money. The reason is that the E2E testing will reduce the probability of having at-sea problems with the deployed systems and also because, if the problems arose at-sea, troubleshooting might not be as costly as in the case of not having the E2E testing capability since the problems would be minor ones. The E2E lab will also support the E2E testing systems engineering concept for the PEO C4I portfolio enterprise engineering such as development, testing, certification, fielding, and sustainment. The purposes of the E2E lab are thus (Musson, 2008b):

- To provide program transparency, team/cross team collaboration, and to speed up delivery.
- To reduce integration risk.
- To provide portfolio block and build recommendations and certifications.
- To implement a distributed, reconfigurable, and dynamic lab environment.
- To allow for a modular design, plug and play, scheduled, cost-effective method of testing.

Additionally, the E2E testing program is envisioned to connect its C4I systems (shown in Table 3) at SPAWAR to other Navy sites' combat systems, such as NSWC

Dahlgren’s Aegis Weapon Systems, NWSC Dam Neck’s ACDS Block 0/1, PAX River’s Airborne systems, and NSWC Rhode Island’s Submarine (Musson, 2008a).

C. E2E TESTING PROGRAM COST

A number of programs with laboratory spaces need to move to different locations to make room (space) available to the E2E lab. As the E2E testing program has to pay for the moves, the total cost of the E2E testing program increases. The E2E lab was to be completed in 2008 at the cost of FY08 $8.5M, which accounts for paying the labs that need to move, paying core engineers, buying the equipment, and building the E2E lab (Williams, 2009). More money is now needed in order for the lab to be completely built. The PEO C4I has promised to provide additional funding to make the E2E testing of the Battle Group effort successful, but the amount of funding has not yet been determined. The cost of keeping and upgrading the E2E lab to support the E2E testing initiative can potentially be high.

The E2E testing program is not currently in the Program Objective Memorandum (POM) fund, which guarantees funding to the program. Presently, the PEO is taxing the PMWs to pay for the E2E testing program (Williams, 2009).

D. E2E TESTING SCHEDULING

The E2E lab should be available for all on a first-come, first-serve basis. A web-based scheduling system has been created to allow the PM or Test Director to schedule his/her tests. Since the E2E lab is still under construction, the availability of the lab has not been established and, therefore, except for the Lincoln Battle Group test re-scheduled in late FY09 by the request of PEO C4I, no tests have been scheduled for FY09 (Williams, 2009).

E. E2E TESTING STAFFING

A lab manager will manage the E2E lab, which will be staffed with the core engineers and technicians who will install, maintain, and operate the lab (Williams, 2009).

F. E2E LAB TEST RESULTS

Since the E2E lab is still being built, except for the connectivity testing between the E2E lab and the other labs on the SSC-PAC campus, no full tests have been conducted. The connectivity test was successful (Aird, 2009).

G. SUMMARY

In summarize, the E2E testing concept is a useful concept for testing C4I systems at the Battle Group integration level before delivering them to the Fleet because the Navy potentially saves money from not conducting testing at sea, which is costly. The idea underlying the E2E testing concept is to be proactive and to correct potential problems in the labs in order to reduce issues at sea. Accordingly, savings will be made, and financial resources can then be allocated to support other efforts. Being able to integrate all the C4I systems in the lab environment would be the first accomplishment, as it did not occur in the past. The future will tell whether this concept will work as anticipated.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS

A. INTRODUCTION

As discussed in Chapters II and III, whereas the participant sites receive funding on a per-test basis in the DEP testing program, the E2E testing program does not pay engineers from the PMWs who conduct tests. Also, as discussed in Chapter III, the E2E lab has not been built yet because management did not have a complete plan to establish the lab. This chapter discusses the results of a qualitative analysis of the DEP testing information and a quantitative analysis of the DEP testing data in order to provide data to aid the DEP testing PM in making decisions on the paying options. It also demonstrates the use of goal programming in proving data to support the creation of a plan for building the E2E lab.

The rest of this chapter is organized as follows. Section B discusses the analysis of the DEP testing program and Section C the E2E testing program. Section D summarizes this chapter.

B. DEP TESTING PROGRAM

With an emphasis in the area of ASW, the DEP is intended to support only testing of Battle Group combat systems. Combat systems have thus far been the subjects of DEP testing, because NAVSEA, which manages not only the DEP program but also the Navy ships, heavily emphasizes combat systems and, in particular, safety associated with firing weapons. As the combat systems are tied to C4I systems, the DEP program needs to add the latter systems to its testing. Strategically, the DEP wants to expand its testing to C4I systems, joint sites and their systems, and commercial sites, such as Northup Grumman, Lockheed Martin, Boeing, and coalition sites and their systems. However, the current DEP budget might not be able to support this expansion (Coyne, 2006). Also, the expansion to the commercial sites has not materialized because the DEP program fails to justify the value added by the commercial sites. No new sites have been added. Even if

the new sites were needed, funding from the sponsors (NAVSEA and OPNAV) would not be available to support the additions. The core sites discussed in Chapter II have thus remained in use.

As pointed out in Chapter II, the DEP participant sites are paid on a per-test basis (Mann, 2004). This pay-per-test concept has led to a major problem for the DEP program, which is the time loss at the beginning of a test. This time loss, meaning the time not used for carrying out the test, is caused by the high personnel turnover rate, which in turn is a consequence of the pay-per-test concept. A site that is to carry out a test will hire part-time engineers to do the testing. Upon completing the test, these engineers, who are no longer funded, move on to other opportunities or to take full-time positions elsewhere. The same phenomenon occurs test after test, resulting in a high personnel turnover rate. When either a test need be repeated or a new test need be performed, newly hired engineers, who have little or no knowledge of the program, spend time to learn and to set up the test, resulting in an ineffective use of the allocated testing time. Furthermore, the time loss is also caused by a few sites having problems, as the rest of the sites have to wait until the troubled sites are fixed before all the sites can carry out the testing.

An analysis of the data captured from the reviewing of the DEP test reports supports the findings described immediately above. The data refer to the uptimes and downtimes of the sites, collected between FY02 to FY06 (OTHT, 2008), shown in Appendix A. The analysis involves the calculation and an examination of the mean times between failures (MTBF) of the sites during this period. The MTBF, which is defined to be the total of downtime minus the total of uptime divided by the number of failures during the indicated period, is calculated according to (Wikipedia).

$$MTBF = \sum \frac{Downtime - Uptime}{\#\, of\ \ Failures}$$

Based on the data in Appendix A, the calculated MTBF equals to 3 hours and 6 minutes, which is roughly 38% of an eight-hour test day. The DEP program needs to reduce or eliminate this large lost time. The outcomes of the interview with the lead (Tran, 2009) indicate that the high turnover rate of the testers at the sites, coupled with

new personnel that are not familiar with the DEP testing environment, contribute to the substantial amount of time lost per test day. The reasons for this high personnel turnover are:

- Engineers are not fully funded and cannot find a part-time project to make up for the short fall.
- It is difficult to split the task between two or more efforts.
- Testers unfamiliar with the test cannot get help since the test is conducted after hours when the experts have already left for the day.
- Formal Risk Mitigation Test (formally called a dry run) has been scaled down from one week to one day, and then to none, in order to save money.

Figure 2, which displays the delays for the tests repeated during the FY02 to FY06 periods, indicates that the first day of each test is the most troublesome day of the entire test period, as it takes more than two hours of every 8-hour test day to get the systems ready, which would be unacceptable for any test. As a mandatory requirement for the sites, the amount of set-up time must be reduced to less than an hour per test day to complete the necessary tests.

The DEP program has been operating since 1999, yet the PM continues to have difficulties in determining whether the program should pay the participant sites full-time funding or per-test amounts. The quantitative analysis, addressed in Chapter V, is used to aid the DEP PM in determining an effective paying option.

Figure 2 also shows that in some cases the test day is completely lost, as reflected by the peaks of the corresponding curves (e.g., FY02, Test 1, and day 8). With the lost time occurring almost daily, the DEP PM should conduct a risk mitigation effort to figure out what the sites can do to reduce the lost time. The management should be held accountable for not conducting such a risk mitigation effort. If one site were unable to support testing, then DEP would be able to utilize the remaining sites.

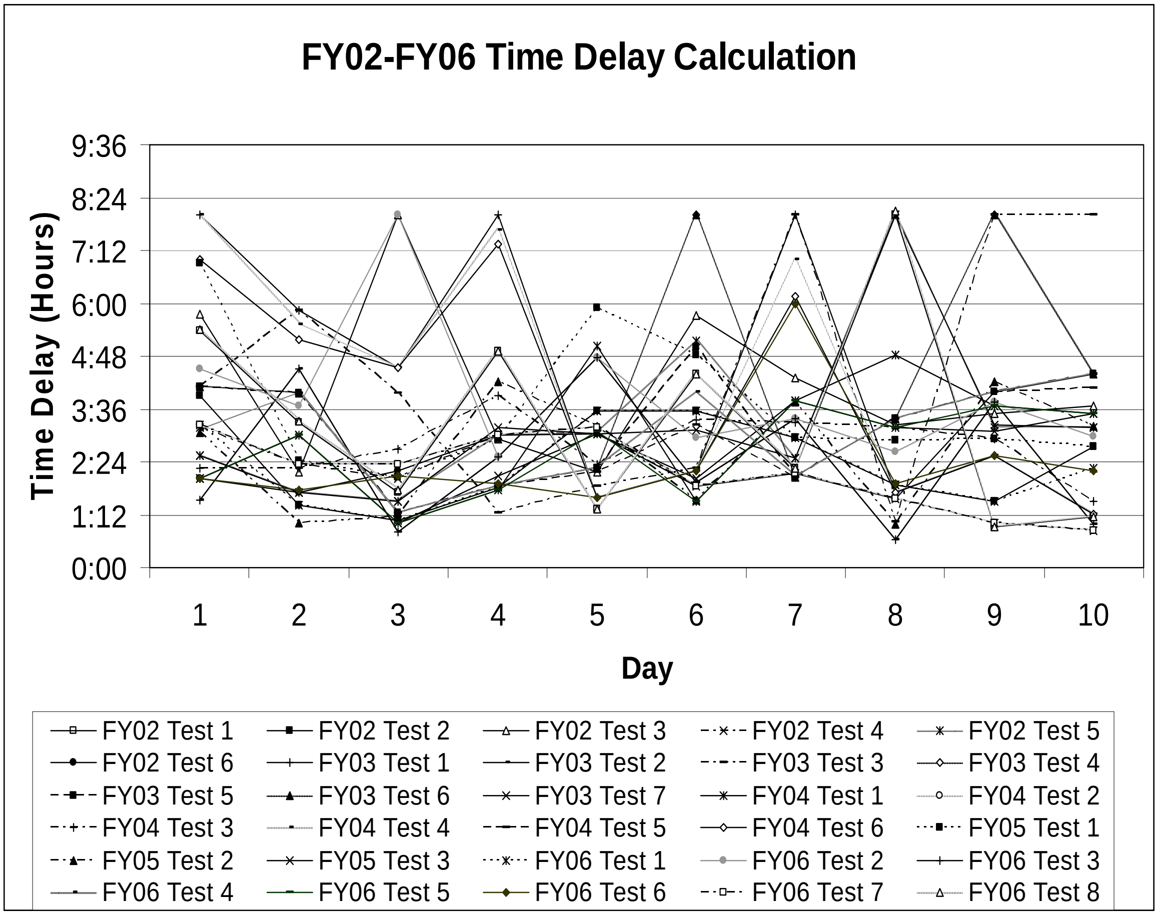

Figure 2. Comparison of Test Delays

C. END-TO-END TESTING PROGRAM

Again, contrary to the DEP program, the E2E testing program is concentrated mainly on C4I systems. The E2E testing program emphasizes the area of services, such as Domain Name Server (DNS)/Email/Web; communication systems, such as Consolidated Afloat Networks and Enterprise Services (CANES)/Advanced Digital Network System (ADNS)/Teleport/Network Operation Center (NOC); Information Assurance (IA), such as Gold Disk/Virtual Private Network (VPN)/Cryptos; and network, such as Satellite Communications (SATCOMs) & Line of Sight (LOS) & Pierside. In the future, E2E testing may be expanded to include systems outside of the C4I arena (E2E, 2008).

As mentioned in Chapter III, the E2E testing has planned to use testers from PMWs. The decision to leverage the PMW testers is flawed because (Aird, 2009):

- The PMW testers would leave after completion of a test and would also take with them their knowledge, which might not be available when needed for additional testing. If problems were discovered from a previous test, the PMW testers would not be around to help with the recreation of the problems. Even if they could, the PMW testers would not be able to help immediately since they might have already been working on different tasks.
- In regards to the expertise of the testers, if the testers were not seasoned testers, then the E2E testing of C4I systems probably would encounter the time loss problems faced by the DEP testing program.
- Leveraging testers from different programs would bring a lack of accountability as each program would claim effectiveness when, in actuality, history has shown otherwise. Also, in the case of failure, a program would blame another program. Furthermore, working across many programs requires timely coordination and flexibility of schedule in order to support the E2E testing program. In addition, gathering all testers from different programs at one time would not be an easy task and an even harder task when the schedules slip to the right (Aird, 2009).

A funding issue arises. The PEO C4I forces the PMWs to support the E2E testing program and taxes their programs to pay the E2E testing. The PMWs, however, argue that their testing capability would be sufficient (Aird, 2009) to support the Fleets and, being short on personnel to support additional tasks, want their programs to be left alone. The PMWs also believe that the E2E testing program should be POM funded, rather than being paid by taxing the PMWs.

Furthermore, future funding secured from taxing the PMWs could not always be certain. The Assistant E2E testing PM is not sure of how much funding or if any funding will be available for FY10 (Williams, 2009). With the funding uncertainty, the E2E testing program might not be sustainable in the future. For example, the Horizontal

Integration program from SPAWAR, which had been funded from taxing PMWs, was terminated upon Adm. Gauss' retirement (Aird, 2009).

The results of the interview with the E2E testing PM (Williams, 2009) reflect the uncertainties the PM has experienced in regards to building the E2E lab with the available funding. The first E2E testing of the Lincoln Battle Group, which was to occur in December 2008 (E2E, 2008), did not take place, because the E2E lab was not ready. In fact, the E2E lab is currently not ready to support any testing, and, because of funding uncertainty, the PM does not know when it will be up and running. In addition, the PM does not have a complete plan to establish the E2E lab, which has contributed to the delay in getting the E2E lab ready. The goal programming approach, addressed in Chapter V, is used to aid the E2E testing PM in determining an effective implementation plan to build the lab.

D. SUMMARY

From the review of the existing literature on the DEP and E2E testing programs and from the interviews with the respective PMs and leads, (1) the DEP pay-per-test concept has led to a major problem of testing inefficiency, namely, the loss of test time to setting up the labs by inexperienced part-time engineers, and (2) the E2E testing program does not have a complete plan to build the E2E lab.

V. COMPARATIVE ANALYSIS AND GOAL PROGRAMMING

A. INTRODUCTION

As noted in Chapter II, the DEP program has been operating since 1999, yet the PM continues to have difficulties in determining whether the program should pay the participant sites full-time funding or per-test amounts. Rather than paying for full-time testers, the DEP PM has chosen the pay-per-test method. The comparative analysis discussed in this chapter aims at providing data to aid the DEP PM in selecting the best paying option for the DEP testing program.

As observed in Chapter III, the E2E lab has not been built. One of the causes of this debacle is the E2E testing PM has failed to determine the funding needed to build the E2E lab and to get it ready to support testing. The goals for E2E testing have not been established and spelled out clearly in the plan to build the E2E lab. To remedy this undesirable situation, this thesis uses goal programming (GP) (Ragsdale, 2007) to establish the goals of the E2E lab in the presence of funding constraints.

The rest of this chapter is organized as follows. Section B presents the results of the comparative analysis of the two paying approach: pay-per-test and pay-full-time. Section C discusses and demonstrates the goal programming approach to aiding in the creation of a plant for building the E2E lab. Section D provides a brief summary of the chapter.

B. COMPARATIVE ANALYSIS

Table 4 shows seven distributed test sites involved in interoperability certification testing: Dahlgren, Dam Neck, NSWC San Diego, NAVAIR, SSC-PAC TADIL, SSC-PAC GCCS-M, and Wallops Island. As discussed in Chapter II, NAVSEA has two paying options for the DEP testing: paying the sites a fixed amount of money to retain full-time testers or paying the sites on a per-test basis. The first option is not necessarily cost-effective, as the sites will constantly deplete resources, specifically funding, whether they are doing testing, or staying idle. The latter paying option might save NAVSEA

money, but as discussed in Chapter IV, it results in 38% of the testing lost to the initial test set-up. Constrained by the available budget, the DEP program must decide between the two paying options. To aid the DEP program in making an informed decision, a comparative analysis is performed this research, in which the DEP data are collected and analyzed, to answer the question as to which pay method—pay-per-test or pay-full-time—the DEP program should use.

The comparison is made for all the years of DEP testing from FY01 to FY09. Figure 3 shows the number of tests carried out in those years, which ranges from three to eight per year. It is noted that less than six tests were carried out in FY01 and FY05, and at least six tests were carried in the remaining years. For the purpose of illustration, FY09, during which eight tests are conducted, is considered for comparing the costs resulting from using the two different methods of payment. The FY09 data shown in Table 4 are input to the comparative analysis. The data (BFIMS, 2009) are:

- The maximum number of engineers at a test site, which is two, to support a test from pre-test through the post-test, and their hourly salary.
- The total test time of two weeks, implying 160 hours for two engineers.
- The time allocated for attending test planning working group meetings (TPWG), working on test plan/procedures, and reviewing test plan/procedures, which totals two and half weeks, implying 200 hours for two engineers.
- The time for pre-test checkout prior to the actual test, which is 32 hours for two engineers.
- The time allocated for post-test draft/final test report and trouble reports input to the database, which is two weeks, implying 160 hours for two engineers.
- The total lost time per test incurred by two engineers, which varies from test to test.
- The total man-hours per year, which is 1750.

NAVSEA DEP PROGRAM								
FY09 Data	NSVC DD	NSVC DN	ICSTD SD	NAVAIR	TADIL SD	GCCS-M SD	NSVC VI	Total Hourly Cost for All Sites ($)
Engineer 1 (Cost Per Hour)	$120	$110	$115	$100	$115	$115	$105	780
Engineer 2 (Cost Per Hour)	$125	$105	$115	$105	$115	$115	$105	785
Pay-Per-Test Option	Hours	Engineer 1 Cost (S)	Engineer 2 Cost ($)	Total Cost				
Test Time (2 Weeks)(Hours)	80							
TPWG (2 1/2 Weeks) (Hours)	100							
Pre-Test Checkout (2 Days) (Hours)	16							
Post Test Data Input/Report (2 Weeks)(Hours)	80							
Total Hours Per-Test	276							
Hourly Cost ($)		780	785					
Total Cost Per-Test (without Lost Time) ($)		215280	216660	$431,940				
Maximum Lost Time Per-Test								
Test 1	24	18720	18840	$37,560				
Test 2	31	24180	24335	$48,515				
Test 3	29	22620	22765	$45,385				
Test 4	37	28860	29045	$57,905				
Test 5	25	19500	19625	$39,125				
Test 6	27	21060	21195	$42,255				
Test 7	14	10920	10990	$21,910				
Test 8	16	12480	12560	$25,040				
Total Cost Per-Test (Plus Lost Time)					Total Pay Per Test Option	Total Pay Full-Time Option		
Test 1				$469,500	$469,500	$2,738,750		
Test 2				$480,455	$949,955	$2,738,750		
Test 3				$477,325	$1,427,280	$2,738,750		
Test 4				$489,845	$1,917,125	$2,738,750		
Test 5				$471,065	$2,388,190	$2,738,750		
Test 6				$474,195	$2,862,385	$2,738,750		
Test 7				$453,850	$3,316,235	$2,738,750		
Test 8				$456,980	$3,773,215	$2,738,750		
8 Tests Total (FY09 Total)				$3,773,215				
Pay-Full-Time Option								
Man Year Hours (1750)	1750	1365000	1373750	$2,738,750				

Table 4. NAVSEA DEP Program FY09 Data

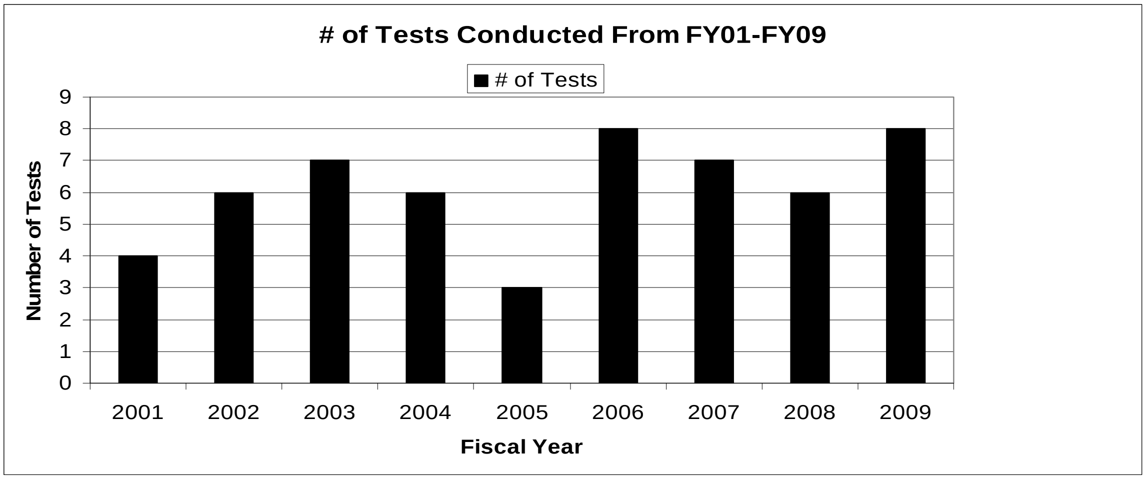

Figure 3. Number of Tests Conducted From FY01-FY09

A calculation using the data in Table 4 shows that, for conducting eight tests during FY09 with two engineers, using the pay-per-test method costs approximately $3.8M whereas using the full-time payment method costs about $2.7M

The same calculation is carried out to obtain the total costs from FY01 to FY09 (BFIMS, 2009), using all but the hourly costs in Table 5 and accounting for the different number of tests from year to year. Figure 4, displaying the costs as a function of the number of tests incurred from using the two paying methods, indicates that if the number of tests per year is not greater than six, the pay-per-test method is cheaper than the pay-full-time option. If more than six tests per year are carried out, the full-time is cheaper than the pay-per-test option. Note that the comparison is made with respect to cost only. Factors other than cost that may play in the decision making process are not considered in this thesis.

Furthermore, as six or less tests are conducted for only two out of the nine years, the pay-full-time option would have collectively saved money during FY01-FY09. In this case, the core experienced engineers would have been likely retained and the lost time would have been reduced, if not avoided. Based on Figure 4, the DEP program would have saved roughly $1.2 M over the FY01-FY09 if the pay-full-time option had been instituted. Thus, in the long run, if more than six tests are conducted, savings will be made with the pay-full-time option.

Pay-Per-Test and Pay-Full-Time Comparison									
FISCAL YEAR	2001	2002	2003	2004	2005	2006	2007	2008	2009
PAY-PER-TEST OPTION									
# Of Test Conducted Per Year	4	6	7	6	3	8	7	6	8
PER-TEST FOR ALL SITES									
Hourly Cost For Eng #1 ($)	517	545	573	604	635	669	704	741	780
Hourly Cost For Eng #2 ($)	521	548	577	607	639	673	708	746	785
Total Hours for Eng #1 (Hours)	276	276	276	276	276	276	276	276	276
Total Hours for Eng #2 (Hours)	276	276	276	276	276	276	276	276	276
Total Cost For Eng #1 (Without Lost Time) ($)	142,821	150,338	158,251	166,580	175,347	184,576	194,290	204,516	215,280
Total Cost For Eng #2 (Without Lost	143,737	151,302	159,265	167,647	176,471	185,759	195,536	205,827	216,660
Total Cost for 2 Engineers (Without Lost	286,558	301,640	317,516	334,227	351,818	370,335	389,826	410,343	431,940
Total Max Lost Time Hours for Each Engineers	35.3	31.0	19.3	24.5	23.7	15.6	19.6	22.0	25.4
Total Lost Max Time Cost for	18,241	16,886	11,058	14,787	15,036	10,449	13,777	16,302	19,793
Total Max Lost Time Cost for	18,358	16,994	11,129	14,882	15,132	10,516	13,866	16,407	19,919
Total Max Lost Time Cost for 2 Engineers ($)	36,598	33,880	22,187	29,669	30,168	20,965	27,643	32,709	39,712
Total Cost for 2 Engineers (With Lost Time) ($)	323,156	335,520	339,702	363,896	381,986	391,300	417,469	443,052	471,652
PER YEAR									
Total Cost Per Year for 2 Engineers ($)	$1,292,625	$2,013,118	$2,377,916	$2,183,374	$1,145,957	$3,130,400	$2,922,281	$2,658,309	$3,773,215
PAY-FULL-TIME OPTION									
Number of Hours Per Year per Engineer	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
Engineer #1 Hourly Cost ($)	517	545	573	604	635	669	704	741	780
Engineer #2 Hourly Cost ($)	521	548	577	607	639	673	708	746	785
Total Cost For Eng #1 ($)	904,750	953,230	1,003,400	1,056,211	1,111,801	1,170,317	1,231,913	1,296,750	1,365,000
Total Cost For Eng #2 ($)	911,750	959,341	1,009,832	1,062,982	1,118,928	1,177,819	1,239,809	1,305,063	1,373,750
Total Cost for 2 Engineers Per Year ($)	$1,816,500	$1,912,571	$2,013,233	$2,119,193	$2,230,729	$2,348,136	$2,471,722	$2,601,813	$2,738,750

Table 5. FY01-FY09 Pay-per-Test vs. Pay-Full-Time

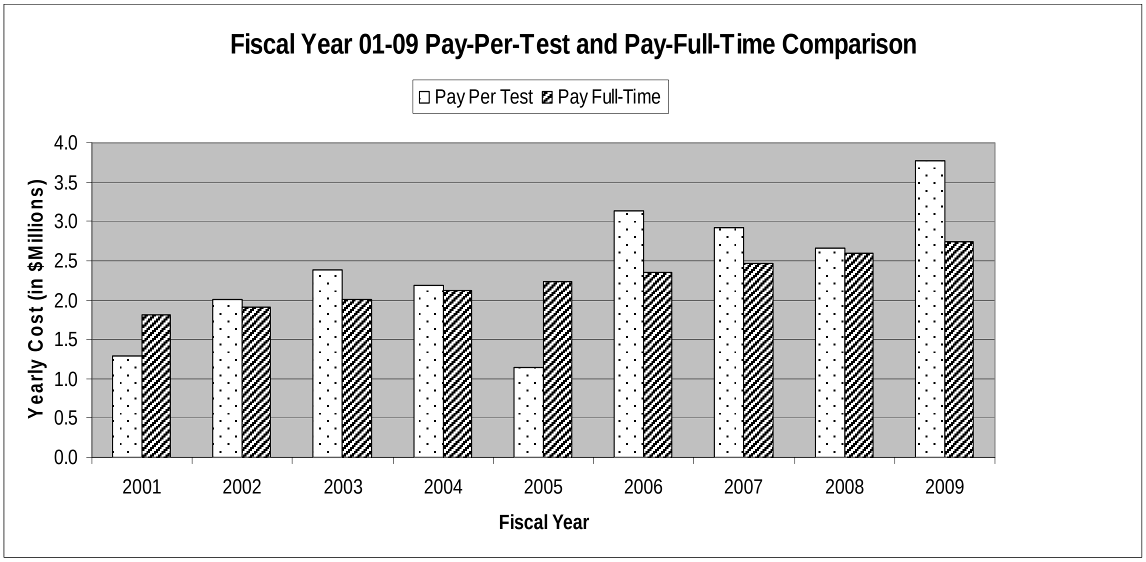

Figure 4. FY01-FY09 Pay-per-Test vs. Pay-Full-Time

C. E2E TESTING PROGRAM

The E2E lab, which was to conduct testing of a battle group by November 2008, is still in the planning phase. The E2E testing program is still determining the funding needed to build the E2E lab and to get it ready to support testing. The funding issue is elaborated in Chapter III. The level of funding depends on the needs (or goals) of the E2E lab, which, as part of the E2E lab building plan, must be determined and supported by a rigorous analysis.

As goals, the lab needs to have desk/chairs, racks, conference rooms, and space. Specifically, for the purpose of illustration, the E2E lab building scenario considered in this thesis requires approximately 40 desks and chairs, 20 computer racks, and 2 conference rooms. The desks/chairs, racks, conference rooms, and the lab require 100, 100, 1,050, and 8,000 ft^2 of space, respectively. Furthermore, the desks/chairs, racks, and conference rooms each cost \$5,000, \$7,000, and \$156,000, respectively. The budget available for the E2E lab is \$650,000.

Regarding meeting these goals, underachieving the first three goals related to the number of desks/chairs, racks, conference rooms would be undesirable, but overachieving these goals would be acceptable. Also, underachieving or overachieving

the goal of adding 8,000 ft^2 would be undesirable. Finally, only spending more than \$650,000 would be undesirable. (The objective function defined below reflects this consideration.)

The question to answer is: Can the E2E testing program deliver the E2E lab that will meet these goals for such a budget? The approach to answering this question is to formulate the E2E testing optimal planning problem as a goal programming problem and to solve the resulting goal programming problem using Excel Solver.

The E2E testing goal programming problem is now formulated. Let X_1 stand for the number of desks and chairs, X_2 the number of computer racks, and X_3 and the number of conference rooms. Let v_1, v_2, v_3, v_4, and v_5 be, respectively, the target values of the number of desks and chairs, the number of computer racks, the number of conference rooms, the total square footage, and the total cost, which are 40, 20, 2, 8,000 ft^2, and \$650,000, respectively. These values are not derived from a rigorous analysis, and they might not be possibly met. To account for this unfounded restrictiveness, let the so-called deviational variables d_i^- and d_i^+, $i = 1, \cdots, 5$, represent the amounts by which the goals can deviate from their respective target values. Specifically, d_1^- represents the amount by which the i^{th} goal's target value is underachieved, and d_1^+ represents the amount by which the i^{th} goal's target value is overachieved.

The constraints are thus:

$$\alpha_{i1} X_1 + \alpha_{i2} X_2 + \alpha_{i3} X_3 + d_i^+ - d_i^+ = v_i$$

$$X_i \in \mathbb{Z} \text{ and } X_i \geq 0$$

$$d_1^+, d_i^+ \geq 0$$

$$i = 1, \cdots, 5.$$

in which, for the E2E testing problem at hand, the coefficients $\alpha_{i1} = \alpha_{i2} = \alpha_{i3} = 1$, $\alpha_{i4} = \alpha_{i5} = 0$, for $i = 1,2, \text{and } 3$, and $\alpha_{41} = \alpha_{42} = 100\, ft^2$, $\alpha_{43} = 1{,}050\, ft^2$, and $\alpha_{51} = \$5{,}000, \alpha_{52} = \$7{,}000, \text{and } \alpha_{53} = \$156{,}000.$ $\mathbb{Z}$ denotes the set of integers; $X_i \in \mathbb{Z}$ and $X_i \geq 0$ together mean that X_i are nonnegative integers.

The objective function is defined as

$$z = \sum_{i=1}^{3} \frac{w_i^-}{v_i} d_i^- + \sum_{i=4}^{5} \frac{w_i^+}{v_i} d_i^+ \ .$$

in which the weight coefficients, w_i^- and $w_i^+, i = 1, \cdots, 5,$ represent numeric constants that can be assigned values to weight the various deviational variables. The objective function is thus a weighted percentage deviation. A variable that represents a highly undesirable deviation from a particular goal is assigned a relatively large weight. A variable that represents a neutral or desirable deviation from a particular goal is assigned a weight of 0 or lower than 0. Analysis of the goal programming begins with $w_1^- = w_2^- = w_3^- = w_4^- = w_4^+ = w_5^+ = 1$ and all other weights being 0.

The E2E testing goal programming problem is thus: Minimize z subject to the constraints above. The solution to this E2E testing goal programming problem is obtained, using Excel Solver (Ragsdale, 2007), and is captured in Table 6.

As indicated by Table 6, the planned cost (budget), which is $650,000, exceeds the optimal cost, which is $647,000, by $3,000. Whereas money savings are realized, the targeted number of desks and chairs is short by one. As aforementioned, this negligible shortage is acceptable.

E2E Goal Programming					
Problem Data	Desk & Chair	Rack	Conference Room		
Square Footage	100	100	1050		
Cost	5000	7000	156000		
Goal Contraints	Desk & Chair	Rack	Conference Room	Sq. Ft.	Cost
Actual Amount	39	20	2	8000	$647,000
Under +	1	0	0	0	$3,000
Over -	0	0	0	0	0
Goal =	40	20	2	8000	$650,000
Target Value	40	20	2	8000	$650,000

Table 6. E2E Testing Goal Programming Solver Results

The E2E testing PM can thus use this formulated problem with different budgets and numbers of items, such as desk/chairs, racks, conference rooms, and space, etc., to come up with the best available minimum cost to support the E2E testing effort. Additionally, the E2E testing PM can use this method to justify the funding for the current year and future funding.

D. SUMMARY

In summary, the comparative analysis indicates that paying the DEP sites full-time will save the DEP program if it conducts six or more tests per year. If the number of tests is less than six per year, then DEP program has the flexibility in selecting either of the paying options. An additional advantage of paying the DEP sites on a full-time basis is that the DEP sites will likely be able to retain experienced testers for a long period of time and hence to be able to keep the continuity and cohesiveness of the team.

Goal programming can be used effectively to aid in establishing a plan for building an E2E lab for the Navy E2E testing. It provides a rigorous approach to determining the goals of the E2E lab in a timely fashion (hence, saving money) that can meet budgetary constraints. It can also be used in support of planning for programs other than testing as well as for many multi-goal problems encountered in systems engineering. Results obtained with this goal programming approach are used in decision making, in assessing the feasibility of achieving the goals, and also in knowing how much funding is required to meet the goals.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSION

Dealing with test and evaluation of combat and C4I systems in the U.S. Navy, this thesis focuses specifically on two separate Navy testing programs managed by two different commands: the DEP testing program, run by NAVSEA, and the E2E testing program, currently being formed by SPAWAR.

During deployments and Battle Group exercises, Battle Group systems encountered interoperability problems such as erroneous dual/multiple track designations, misidentification/track identity conflicts, report responsibility conflicts, friendly tracks displayed as unknown/pending, tracks dropped without operator action, different track identities of different ships, etc. When these interoperability problems occurred at sea, fixing them was costly because of the high cost incurred in bringing SMEs from land to ships to correct the problems. In an effort to prevent these costly problems, the DEP testing program was formed in June 1998 to support the evaluation of the interoperability of Battle Group systems and also to aid in design decision making early in the systems acquisition process. The DEP consists of shore-based combat system sites, which are currently paid on a per-test basis, rather than on a retaining full-time basis.

The purpose of the E2E testing is to evaluate integrated capabilities of shipboard C4I systems for interoperability. The shipboard C4I systems need be tested before their delivery to the warships. Not only does E2E testing support the certification, but it also supports the developmental testing of multiple programs. In the future, the E2E testing may be expanded to include systems outside of the C4I arena. In the E2E testing concept, formulated in 2007, a single E2E systems engineering laboratory, which is yet to be built, replicates and tests these C4I systems. Limited in funding, the E2E testing program plans to employ test engineers from the PMW organizations. A challenge faced by the E2E testing program is building and getting the E2E lab ready for testing. Two factors contributing to this challenge are uncertain availability of funding for building the E2E lab and the lack of a comprehensive plan to establish the E2E lab.

With a focus on the issue of cost-effective implementation of the DEP and E2E testing programs, the research performed in this thesis involves (1) conducting a review

of the past and current test results of the distributed, E2E programs and their archived documents, related distributed and E2E testing studies, and other pertinent related material such as test report, test plans, and test procedures; (2) developing interview questionnaires directed at managers of the DEP and E2E testing programs, (3) conducting interviews with the DEP and E2E testing PMs, test directors, and functional leads and process literature and interview results; and (4) performing qualitative and quantitative analysis and goal programming to aid in determining the optimal costs of carrying out these testing methods. The findings from this research follow.

The DEP program currently pays the DEP participant sites on a per-test basis. As a result, the allocated testing time is not fully used for testing; roughly 38% of the allocated testing time is lost at the beginning of a test. Another paying option for the DEP program to consider is paying the DEP participant sites a fixed amount of money to retain full-time engineers. The testing cost data from FY01 to FY09 indicate that conducting eight tests during FY09 with two engineers, using the pay-per-test method costs approximately $3.8M, whereas using the full-time payment method costs about $2.7M, and that if the number of tests per year is not greater than six, the pay-per-test method is cheaper than the pay-full-time option. As six or less tests were conducted for only two out of the nine years (FY01 and FY05), the pay-full-time option would have collectively saved money during FY01-FY09. Thus, in the long run, if more than six tests are conducted, savings will be made with the pay-full-time option.

Using testers from the PMWs to conduct the E2E testing would possibly lead to the time loss problem faced by the DEP program, as the PMW testers would leave after completion of the testing and would also take with them their knowledge; a lack of accountability as different programs from which testers come would claim effectiveness when, in actuality, history has shown otherwise; finger pointing in the case of failure; difficulty in timely coordination and flexibility of schedule in order to support the E2E testing program; and possibly not meeting the schedule. Rather being POM funded, the E2E testing program secures its funding from taxing the PMWs. As such funding is uncertain, the E2E testing program might not be sustainable in the future. Funding uncertainty and the lack of a complete plan to establish the E2E lab contribute to the

delay in building and getting the E2E lab ready for testing. Finally, goal programming can be used as a rigorous approach to determining the goals of the E2E lab in a timely fashion (hence, saving money) that can meet budgetary constraints. For the scenario treated in this research, the planned cost for building the E2E lab, which is $650,000, exceeds the optimal cost obtained with the goal programming approach, which is $647,000, by $3,000. Whereas money savings are realized, the targeted number of desks and chairs is short by one. This negligible shortage is acceptable. The E2E testing program can use this approach to justify the funding for the current year and future funding.

It is recommended that (1) the DEP sites be funded on a pay-per-test basis if no more than six tests are performed in a year and on a full-time basis otherwise; (2) the core engineers be retained to run DEP tests; (3) optimization techniques in general and goal programming in particular be employed in planning for and, specifically, in formulating a plan for building the E2E lab; and (4) rigorous approaches—analytical and/or optimization techniques—be employed from the beginning of testing programs to plan for and implement the testing programs.

Some areas for further research include (1) extending the analysis and optimization techniques discussed in this thesis to determine the optimal methods of conducting tests with constraints on resources such as laboratories, personnel, schedules, etc. and (2) using the approach espoused in this thesis as a foundation for additional research and studies of the joint distributed testing/coalition distributed testing.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. DEP TEST DELAY DATA (FY02-FY06)

FY02				
Test 1		**Start Loading (h:mm)**	**End Loading (Start to test) (h:mm)**	**Different (h:mm)**
Week 1	Day 1	21:00	2:22	5:22
	Day 2	21:00	0:17	3:17
	Day 3	21:00	22:12	1:12
	Day 4	21:00	1:25	4:25
	Day 5	21:00	22:28	1:28
Week 2	Day 1	21:00	1:20	4:20
	Day 2	21:00	23:15	2:15
	Day 3	21:00	4:20	7:20
	Day 4	21:00	21:15	0:15
	Day 5	21:00	22:10	1:10
Average				**3:06**
Test 2				
Week 1	Day 1	21:00	0:30	3:30
	Day 2	21:00	23:20	2:20
	Day 3	21:00	23:02	2:02
Week 2	Day 1	21:00	0:01	3:01
	Day 2	21:00	0:02	3:02
	Day 3	21:00	22:11	1:11
Week 3	Day 1	21:00	23:09	2:09
	Day 2	21:00	22:33	1:33
	Day 3	21:00	22:40	1:40
	Day 4	21:00	21:51	0:51
Average				**2:07**
Test 3				
Week 1	Day 1	21:00	5:00	8:00
	Day 2	21:00	2:01	5:01
	Day 3	21:00	1:03	4:03
Week 2	Day 1	21:00	5:00	8:00
	Day 2	21:00	22:05	1:05
	Day 3	21:00	23:12	2:12
Week 3	Day 1	21:00	4:15	7:15
	Day 2	21:00	22:02	1:02
	Day 3	21:00	23:11	2:11
	Day 4	21:00	22:12	1:12
Average				**4:00**
Test 4				

Week 1	Day 1	21:00	1:07	4:07
	Day 2	21:00	0:57	3:57
	Day 3	21:00	22:15	1:15
Week 2	Day 1	21:00	22:31	1:31
	Day 2	21:00	22:16	1:16
	Day 3	21:00	5:00	8:00
Week 3	Day 1	21:00	23:03	2:03
	Day 2	21:00	0:03	3:03
	Day 3	21:00	5:00	8:00
	Day 4	21:00	1:03	4:03
Average				**3:43**
Test 5				
Week 1	Day 1	21:00	22:22	1:22
	Day 2	21:00	0:01	3:01
	Day 3	21:00	22:01	1:01
	Day 4	21:00	23:05	2:05
Week 2	Day 1	21:00	0:02	3:02
	Day 2	21:00	23:01	2:01
	Day 3	21:00	0:07	3:07
Week 3	Day 1	21:00	0:10	3:10
	Day 2	21:00	0:05	3:05
	Day 3	21:00	0:00	3:00
Average				**2:29**
Test 6				
Week 1	Day 1	21:00	23:55	2:55
	Day 2	21:00	23:15	2:15
	Day 3	21:00	23:42	2:42
	Day 4	21:00	0:55	3:55
	Day 5	21:00	23:50	2:50
Week 2	Day 1	21:00	0:52	3:52
	Day 2	21:00	0:57	3:57
	Day 3	21:00	0:50	3:50
	Day 4	21:00	23:55	2:55
	Day 5	21:00	23:30	2:30
Average				**3:10**

FY03				
Test 1		**Start Loading**	**End Loading (Start to test)**	**Different**
Week 1	Day 1	21:00	0:05	3:05
	Day 2	21:00	22:35	1:35

	Day 3	21:00	22:04	1:04
	Day 4	21:00	22:49	1:49
Week 2	Day 1	21:00	0:44	3:44
	Day 2	21:00	0:34	3:34
	Day 3	21:00	23:57	2:57
Week 3	Day 1	21:00	22:33	1:33
	Day 2	21:00	22:31	1:31
	Day 3	21:00	23:15	2:15
Average				**2:18**
Test 2				
Week 1	Day 1	21:00	23:03	2:03
	Day 2	21:00	22:12	1:12
	Day 3	21:00	22:27	1:27
	Day 4	21:00	0:01	3:01
	Day 5	21:00	0:02	3:02
Week 2	Day 1	21:00	1:08	4:08
	Day 2	21:00	23:00	2:00
	Day 3	21:00	5:00	8:00
	Day 4	21:00	0:10	3:10
	Day 5	21:00	0:10	3:10
Average				**2:24**
Test 3				
Week 1	Day 1	21:00	22:32	1:32
	Day 2	21:00	0:10	3:10
	Day 3	21:00	22:48	1:48
	Day 4	21:00	22:31	1:31
	Day 5	21:00	0:07	3:07
Week 2	Day 1	21:00	22:45	1:45
	Day 2	21:00	0:23	3:23
	Day 3	21:00	21:38	0:38
	Day 4	21:00	0:05	3:05
	Day 5	21:00	21:59	0:59
Average				**2:06**
Test 4				
Week 1	Day 1	21:00	1:07	4:07
	Day 2	21:00	0:07	3:07
	Day 3	21:00	22:15	1:15
	Day 4	21:00	22:51	1:51
	Day 5	21:00	23:16	2:16
Week 2	Day 1	21:00	1:30	4:30
	Day 2	21:00	23:03	2:03
	Day 3	21:00	0:23	3:23
	Day 4	21:00	0:10	3:10
	Day 5	21:00	1:23	4:23
Average				**3:00**
Test 5				
Week 1	Day 1	21:00	23:02	2:02

	Day 2	21:00	0:11	3:11
	Day 3	21:00	22:01	1:01
	Day 4	21:00	22:45	1:45
Week 2	Day 1	21:00	1:02	4:02
	Day 2	21:00	22:31	1:31
	Day 3	21:00	0:47	3:47
Week 3	Day 1	21:00	0:20	3:20
	Day 2	21:00	0:48	3:48
	Day 3	21:00	0:38	3:38
Average				**2:48**
Test 6				
Week 1	Day 1	21:00	5:00	8:00
	Day 2	21:00	2:11	5:11
	Day 3	21:00	1:33	4:33
Week 2	Day 1	21:00	4:10	7:10
	Day 2	21:00	22:35	1:35
	Day 3	21:00	23:12	2:12
Week 3	Day 1	21:00	4:00	7:00
	Day 2	21:00	22:42	1:42
	Day 3	21:00	23:32	2:32
	Day 4	21:00	22:12	1:12
Average				**4:06**
Test 7				
Week 1	Day 1	21:00	4:00	7:00
	Day 2	21:00	2:11	5:11
	Day 3	21:00	1:33	4:33
	Day 4	21:00	4:00	7:00
	Day 5	21:00	22:35	1:35
Week 2	Day 1	21:00	23:12	2:12
	Day 2	21:00	2:10	5:10
	Day 3	21:00	22:42	1:42
	Day 4	21:00	23:32	2:32
	Day 5	21:00	22:12	1:12
Average				**3:48**

FY04				
Test 1		**Start Loading**	**End Loading (Start to test)**	**Different**
Week 1	Day 1	21:00	2:46	5:46
	Day 2	21:00	23:10	2:10
	Day 3	21:00	5:00	8:00

	Day 4	21:00	23:55	2:55
	Day 5	21:00	23:10	2:10
Week 2	Day 1	21:00	2:44	5:44
	Day 2	21:00	1:19	4:19
	Day 3	21:00	0:15	3:15
	Day 4	21:00	0:20	3:20
	Day 5	21:00	0:24	3:24
Average				**4:06**
Test 2				
Week 1	Day 1	21:00	22:02	1:02
	Day 2	21:00	22:42	1:42
	Day 3	21:00	23:12	2:12
	Day 4	21:00	0:01	3:01
	Day 5	21:00	0:02	3:02
Week 2	Day 1	21:00	22:11	1:11
	Day 2	21:00	23:09	2:09
	Day 3	21:00	22:33	1:33
	Day 4	21:00	0:10	3:10
	Day 5	21:00	0:03	3:03
Average				**2:12**
Test 3				
Week 1	Day 1	21:00	1:07	4:07
	Day 2	21:00	1:01	4:01
	Day 3	21:00	0:27	3:27
	Day 4	21:00	22:15	1:15
Week 2	Day 1	21:00	22:51	1:51
	Day 2	21:00	23:16	2:16
	Day 3	21:00	5:00	8:00
Week 3	Day 1	21:00	22:03	1:03
	Day 2	21:00	5:00	8:00
	Day 3	21:00	5:00	8:00
Average				**4:12**
Test 4				
Week 1	Day 1	21:00	1:07	4:07
	Day 2	21:00	0:47	3:47
	Day 3	21:00	22:15	1:15
Week 2	Day 1	21:00	22:51	1:51
	Day 2	21:00	23:16	2:16
	Day 3	21:00	5:00	8:00
Week 3	Day 1	21:00	23:03	2:03
	Day 2	21:00	0:23	3:23
	Day 3	21:00	5:00	8:00
	Day 4	21:00	0:23	3:23
Average				**3:48**
Test 5				
Week 1	Day 1	21:00	0:15	3:15
	Day 2	21:00	23:20	2:20

	Day 3	21:00	23:20	2:20
Week 2	Day 1	21:00	0:51	3:51
	Day 2	21:00	0:55	3:55
	Day 3	21:00	22:51	1:51
Week 3	Day 1	21:00	23:19	2:19
	Day 2	21:00	22:33	1:33
	Day 3	21:00	23:50	2:50
	Day 4	21:00	21:51	0:51
Average				**2:30**
Test 6				
Week 1	Day 1	21:00	1:07	4:07
	Day 2	21:00	0:57	3:57
	Day 3	21:00	22:15	1:15
	Day 4	21:00	22:01	1:01
	Day 5	21:00	23:10	2:10
Week 2	Day 1	21:00	0:15	3:15
	Day 2	21:00	23:03	2:03
	Day 3	21:00	0:13	3:13
	Day 4	21:00	1:00	4:00
	Day 5	21:00	1:05	4:05
Average				**2:54**

FY05				
Test 1		**Start Loading**	**End Loading (Start to test)**	**Different**
Week 1	Day 1	21:00	3:55	6:55
	Day 2	21:00	23:25	2:25
	Day 3	21:00	23:04	2:04
	Day 4	21:00	23:55	2:55
Week 2	Day 1	21:00	2:54	5:54
	Day 2	21:00	1:49	4:49
	Day 3	21:00	23:57	2:57
Week 3	Day 1	21:00	23:43	2:43
	Day 2	21:00	23:35	2:35
	Day 3	21:00	23:45	2:45
Average				**3:36**
Test 2				
Week 1	Day 1	21:00	23:28	2:28
	Day 2	21:00	22:42	1:42
	Day 3	21:00	22:31	1:31
	Day 4	21:00	0:11	3:11
	Day 5	21:00	0:02	3:02
Week 2	Day 1	21:00	0:08	3:08

	Day 2	21:00	23:30	2:30
	Day 3	21:00	5:00	8:00
	Day 4	21:00	0:15	3:15
	Day 5	21:00	0:10	3:10
Average				**2:30**
Test 3				
Week 1	Day 1	21:00	1:30	4:30
	Day 2	21:00	0:40	3:40
	Day 3	21:00	5:00	8:00
	Day 4	21:00	23:31	2:31
	Day 5	21:00	1:47	4:47
Week 2	Day 1	21:00	23:37	2:37
	Day 2	21:00	0:23	3:23
	Day 3	21:00	23:38	2:38
	Day 4	21:00	0:45	3:45
	Day 5	21:00	23:39	2:39
Average				**4:00**

FY06				
Test 1		**Start Loading**	**End Loading (Start to test)**	**Different**
Week 1	Day 1	21:00	0:04	3:04
	Day 2	21:00	22:00	1:00
	Day 3	21:00	22:09	1:09
	Day 4	21:00	0:13	3:13
	Day 5	21:00	0:03	3:03
Week 2	Day 1	21:00	22:32	1:32
	Day 2	21:00	0:15	3:15
	Day 3	21:00	21:59	0:59
	Day 4	21:00	0:03	3:03
	Day 5	21:00	0:13	3:13
Average				**2:12**
Test 2				
Week 1	Day 1	21:00	0:15	3:15
	Day 2	21:00	22:25	1:25
	Day 3	21:00	22:04	1:04
	Day 4	21:00	22:49	1:49
Week 2	Day 1	21:00	0:34	3:34
	Day 2	21:00	0:04	3:04
	Day 3	21:00	23:17	2:17
Week 3	Day 1	21:00	22:53	1:53
	Day 2	21:00	22:31	1:31
	Day 3	21:00	23:15	2:15

Average				**2:12**
Test 3				
Week 1	Day 1	21:00	22:32	1:32
	Day 2	21:00	1:30	4:30
	Day 3	21:00	21:48	0:48
	Day 4	21:00	23:31	2:31
	Day 5	21:00	1:47	4:47
Week 2	Day 1	21:00	22:57	1:57
	Day 2	21:00	0:23	3:23
	Day 3	21:00	21:38	0:38
	Day 4	21:00	0:45	3:45
	Day 5	21:00	21:59	0:59
Average				**2:30**
Test 4				
Week 1	Day 1	21:00	0:07	3:07
	Day 2	21:00	0:57	3:57
	Day 3	21:00	22:15	1:15
	Day 4	21:00	22:51	1:51
	Day 5	21:00	23:16	2:16
Week 2	Day 1	21:00	1:00	4:00
	Day 2	21:00	23:03	2:03
	Day 3	21:00	0:23	3:23
	Day 4	21:00	1:00	4:00
	Day 5	21:00	1:15	4:15
Average				**3:00**
Test 5				
Week 1	Day 1	21:00	23:02	2:02
	Day 2	21:00	0:00	3:00
	Day 3	21:00	22:01	1:01
	Day 4	21:00	22:45	1:45
Week 2	Day 1	21:00	0:05	3:05
	Day 2	21:00	22:31	1:31
	Day 3	21:00	0:07	3:07
Week 3	Day 1	21:00	0:10	3:10
	Day 2	21:00	0:05	3:05
	Day 3	21:00	0:20	3:20
Average				**2:30**
Test 6				
Week 1	Day 1	21:00	23:02	2:02
	Day 2	21:00	22:45	1:45
	Day 3	21:00	23:05	2:05
Week 2	Day 1	21:00	22:55	1:55
	Day 2	21:00	22:35	1:35
	Day 3	21:00	23:12	2:12
Week 3	Day 1	21:00	3:00	6:00
	Day 2	21:00	22:45	1:45
	Day 3	21:00	23:32	2:32

	Day 4	21:00	23:12	2:12
Average				**2:24**
Test 7				
Week 1	Day 1	21:00	0:15	3:15
	Day 2	21:00	23:20	2:20
	Day 3	21:00	23:57	2:57
Week 2	Day 1	21:00	0:01	3:01
	Day 2	21:00	0:10	3:10
	Day 3	21:00	22:51	1:51
Week 3	Day 1	21:00	23:09	2:09
	Day 2	21:00	22:33	1:33
	Day 3	21:00	22:55	1:55
	Day 4	21:00	21:51	0:51
Average				**2:18**
Test 8				
Week 1	Day 1	21:00	2:25	5:25
	Day 2	21:00	0:19	3:19
	Day 3	21:00	22:45	1:45
	Day 4	21:00	1:55	4:55
	Day 5	21:00	22:20	1:20
Week 2	Day 1	21:00	1:23	4:23
	Day 2	21:00	23:10	2:10
	Day 3	21:00	5:05	8:05
	Day 4	21:00	21:55	0:55
	Day 5	21:00	22:50	1:50
Average				**3:24**

Mean Time between Failures				***3:06***

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Avarez, Kristen, "Fiscal Year 2007 SEATASK for DEP Final," Technical Report, Naval Sea Systems Command (NAVSEA), September 1, 2006.

Aird, Thomas, Interview with the End-to-End Laboratory Lead for the Command and Control Department, unpublished interview, SPAWAR Systems Center-Pacific (San Diego, California), March 16, 2009.

Battle Force Interoperability Management Systems (BFIMS) Web site, https://t308_depweb.nswc.navy.mil , September 3, 2009.

Coyne, Kevin, "The Navy Distributed Engineering Plant (DEP) Strategic Plan for the Fiscal Year 2007 and beyond, Rev 1," Naval Sea Systems Command (NAVSEA), August 24, 2006.

"Distributed Engineering Plant (DEP) Battle Force Interoperability Test (BFIT) Instructions," Naval Sea Systems Command (NAVSEA), July 2005.

"End to End System Engineering (E2E SE) Lab Strategy Vision and Framework," Issue Brief, SPAWAR Systems Center-Pacific (San Diego, California), May 20, 2008.

Mahon, John, "Distributed Engineering Plant (DEP) Battle Force Interoperability Test (BFIT) Semi-Annual Report," Naval Sea Systems Command (NAVSEA), April 2003a.

Mahon, John, "Distributed Engineering Plant (DEP) Battle Force Interoperability Test (BFIT) Semi-Annual Report," Naval Sea Systems Command (NAVSEA), October 2003b.

Mann, Paul, "Fiscal Year 2005 SEATASK for DEP Final," Technical Report, Naval Sea Systems Command (NAVSEA), September 29, 2004.

Miller, Chris, "PEOC4I Governance CONOPS, End-to-End Systems Engineering Team," Space and Naval Warfare Systems Command (SPAWAR), June 02, 2008.

Monteith, Greg, "The Navy Distributed Engineering Plant (DEP) Overview and History," Issue Brief, Naval Surface Warfare Center Dahlgren, December 2001.

Musson, Steve, "Strategy for Collaborative Engineering and Certification Environment Vision and Framework," Issue Brief, SPAWAR Systems Center-Pacific (San Diego, California), January 22, 2008a.

Musson, Steve, "End-to-End System Engineering (E2E SE)," Issue Brief, SPAWAR Systems Center-Pacific (San Diego, California), May 20, 2008b.

Over the Horizon Targeting (OTHT) Web site, https://otht.spawar.navy.mil/ , July 9, 2008.

Ragsdale, Cliff T., “*Spreadsheet Modeling & Decision Analysis: A Practical Introduction to Management Science*, *5e*,” Thompson South-Western, Ohio, 2007.

Seaver, Andrian, “Distributed Engineering Plant (DEP) Force Interoperability Test (FIT) Semi-Annual Report,” Naval Sea Systems Command (NAVSEA), April 2004a.

Seaver, Andrian, “Distributed Engineering Plant (DEP) Force Interoperability Test (FIT) Semi-Annual Report,” Naval Sea Systems Command (NAVSEA), December 2004b.

Tran, Viet, Interview with the DEP Engineering Lead for the Command and Control Department, unpublished interview, SPAWAR Systems Center-Pacific (San Diego, California), March 19, 2009.

Wikipedia Web site, http://en.wikipedia.org/wiki/Mean_time_between_failures/ , June 19, 2009.

Williams, Mark, Interview with the End-to-End Deputy PM for the Command and Control Department, unpublished interview, SPAWAR Systems Center-Pacific (San Diego, California), February 20, 2009.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Dr. Thomas V. Huynh
   Systems Engineering Department
   Naval Postgraduate School
   Monterey, California

4. Dr. Gary McCown
   SPAWARSYSCEN PACIFIC
   San Diego, California

5. Thomas Aird
   SPAWARSYSCEN PACIFIC
   San Diego, California

6. Linh Nguyen
   SPAWARSYSCEN PACIFIC
   San Diego, California